FACILITATING SUSTAINABILITY OF A PRODUCT'S LIFECYCLE IMPACT IN THE EARLY STAGES OF PRODUCT DEVELOPMENT

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FACILITATING SUSTAINABILITY OF A PRODUCT'S LIFECYCLE IMPACT IN THE EARLY STAGES OF PRODUCT DEVELOPMENT

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Abstract

Due to the higher potential impact on a product's sustainability, this research focuses on the early stages of the design process, and the delivery of simplified information to assist and guide designers in their decision-making process. A specific tool (Trophec) was developed with a 'soft modelling' approach as its main characteristic, which delivers a holistic perspective of the life cycle of a given product.

Evidence was found indicating that around 80% of a product's environmental impact can be traced back to the early stages of design, when designers work in a very intuitive, rapid and conceptual way. Furthermore, dozens of 'eco-design' tools, guides, checklist and working frames were explored. Existing research into some of these 'eco-design' tools has found that they were mainly used, or provided assistance to designers, at late stages of product development, when the product has already been conceived and many decisions have been made and subsequent compromises decided upon. These tools do not seem to respond appropriately to the culture and needs of designers in early stages. Moreover, these tools are not being used among other reasons because of their complexity and/or requirement of investing long periods of time and specialised knowledge.

A test was developed in order to detect any influence of the tool in the designers' working processes, in which graduate, undergraduate students and professional designers participated. The protocol consisted of a design task with a 'think aloud' method. The task was completed with a semi-structured interview. In parallel to these tests, the web-based tool was open to the public, registering data from more than 400 users from all over the World.

These tests showed evidence related to designers not voluntarily incorporating sustainability criteria into their projects, as they perceive this activity as optional and to add later on the process, once the product is defined. Important statements were made in the interviews, in relation to the limited capability of designers to truly influence the outcome of the entire design process, understanding that some issues of it are determined by other departments or professionals within a company, normally management and marketing. All the previous supports findings in the literature review and highlight little change in the last 10 to 15 years.

As major contribution of this research, stands the novel method used to capture, analyse and visualise the designers' working processes, as well as the identification of certain basic conditions for the future testing and analysis of 'soft modelling' tools at early stages of new product development.

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Declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the Department of Design Ethics Committee on 13 June 2014.

I declare that the Word Count of this Thesis is 74,845 words

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Chapter 1 – INTRODUCTION

This research project started with the author's interest in finding guidelines for a sustainable car industry, as a result of professional experience and personal interest in complexity and systems theory as foundational elements to achieve a sustainable development. This first chapter will give the reader a first approach to this process and the decisions and actions taken during the entire research.

1.1 - BACKGROUND: MORE THAN ENVIRONMENTAL CONCERNS

The design profession has experienced a profound evolution since the introduction of computers, and later on, even more with the creation of the Internet. Designers are not alone in this; all professions have gone through an explosion on working speed, and particularly in access to knowledge and information. Within this flow of information, the spread of new ideologies and scientific discoveries have brought awareness as well as facts and evidence, that the current patterns of production and consumption of goods are undeniably unsustainable in the long term. Despite this and a large body of work to aid designers improve their products' sustainability, little seems to be changing; the levels of pollution (IPCC 2013), loss of biodiversity (Purvis and Hector 2000) and social inequality (Freeland 2013) increase constantly, our energy-dependency seems to be becoming more extreme (Smil 2000).

Although the concept of sustainability is not new, it is in this growing access to knowledge that has also spread among the general population, and has become a common word, in many cases misused and abused. Nevertheless, the concept of sustainability has gone through its own evolutionary process, somehow originally intended to express concerns for the exponential decay of certain aspects of the Earth's environment, mostly directly correlated to human activities. One of the master works on this belongs to Rachel Carson (1962) with her book 'Silent Spring'.

In 1987 the United Nations produced 'Our Common Future', also known as the 'Brundtland Report' (WCED 1987), after the chair of the commission Gro Harlem Brundtland. This influential report had the intention to set the discussion of the environment and development as one unified theme. For it they proposed a triple perspective on sustainability: environmental, economical and social. After this report many other authors have reinterpreted these three factors, one relevant to mention is John Elkington's triple bottom line of: people, planet and profit (Elkington 1998).

Within this triple perspective, in the literature review chapter of this document, several authors will be reviewed discussing that the required change is structural in character and the macro-economic model at its core. This model has been questioned since its conception, one of the first and more renowned was Thomas Malthus (Eatwell, Milgate et al. 1987). As in the 18th century there was a popular belief that mankind could improve limitlessly, economically and technologically, Malthus was concerned about the linkage between that improvement and the consumption of natural resources, he saw endless population growth as a great danger. His work influenced highly relevant figures like Darwin, Keynes and Marx among many others (Kishtainy, Abbot et al. 2012).

Being that economics is at the core of this discussion, it is relevant to mention that the most widely used method for measuring economic progress is the Gross Domestic Product (GDP). Nevertheless, it's creator, Simon Kuznets stated in the US congress in 1934 that 'the welfare of a nation can scarcely be inferred from a measure of national income' (Kuznets 1934). Daly and Farley defined GDP as: "the sum of all value added to raw materials by labour and capital at each stage of production, during a given year". From this definition it can be inferred that the more efficient the labour is, and less capital is needed, the more added value can be achieved. This principle drives technological improvements, and underpins a continuous search for efficiency; which in turn creates another complex linkage with the balance of unemployment (Jackson 2009). In order to keep people employed and avoid social collapse more products must be created and consumed, this is just one of the reasons why economies are, therefore, constrained to always seek growth.

This trend is well defined by Jevons' paradox, where technological efficiency instead of easing pressure on the planet and people, creates more demand, consumption and dependency. The way we design, build and use products, and even keep social cohesion is based on a constant structural need for avoiding collapse, fed by positive feedback loop that only increases its negative impacts.

The measurement of economic growth regularly ignores one crucial factor: the level of well-being in people. A strong evidence of this can be found in the relationship between the Human Development Index (HDI) and GDP per capita. Figure 1.1 shows that after a certain level of income is achieved, little or no improvement on human development can be seen, yet increase in GDP is the main objective of the great majority of the World's governments. This figure also clearly shows a greater density of low-income countries and hence, illustrates a deep unevenness that the current macro-economic system has been unable to change (UNDP 2010).

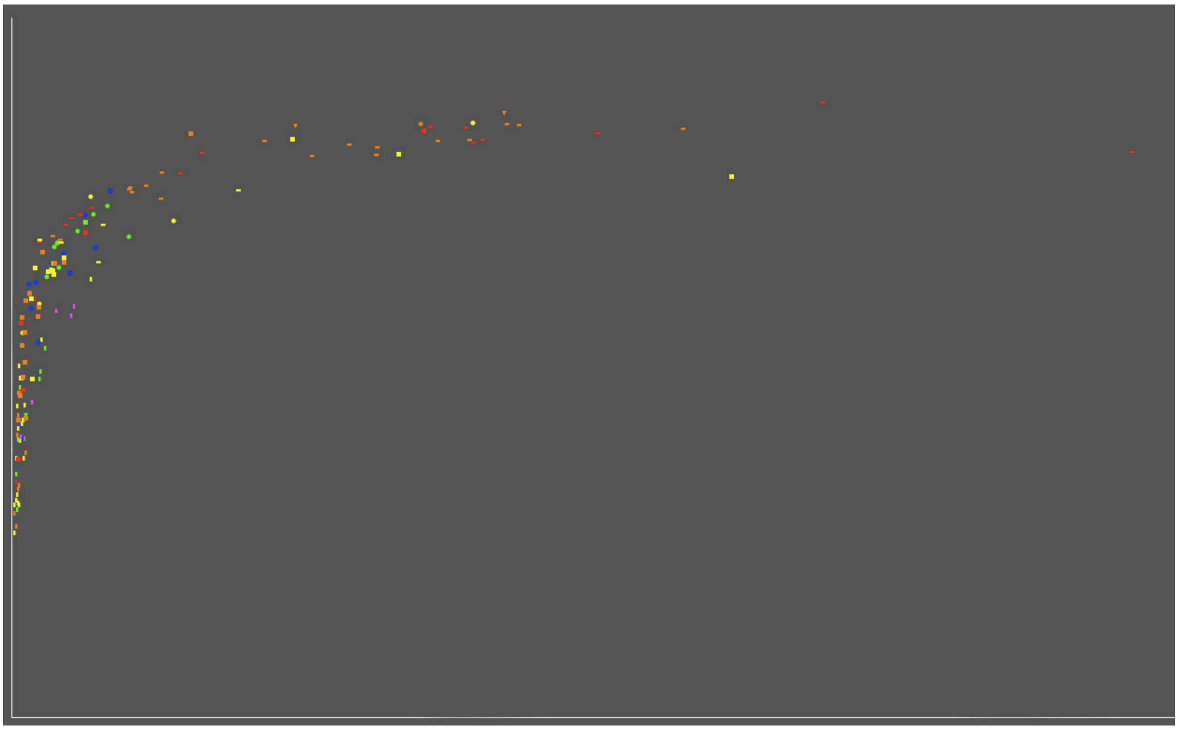


Fig. 1.1 The top 167 economies. GDP per capita as horizontal axis and Human Development Index as vertical axis. After (UN 2014).

Well-being is a highly polemic and subjective concept, defining precisely and agreeing what constitutes human well-being has not yet been achieved. There are several alternative measurement indexes (Talberth, Cobb et al. 2006, Addallah, Thompson et al. 2009, CfBS 2014), but these regularly deal with intangible and hard to measure factors like contentment or fulfilment. One often found in literature, mentioned above, the HDI created by the UN, measures basic minimum components of human development, like education, health and gender equity.

From all these considerations some counter-current economists have frequently raised the question: what size should the economy be? (Daly 1992). If it is accepted that macroeconomics is not an isolated system but a subsystem dependant on the Earth's ecosystem services, (Daly 1991) it is physically impossible to sustain perennial growth within the current model. With this idea present, size and distribution of businesses become key to achieving long term sustainability (GundInstitute 2011), as well as to empower local development, biological and cultural diversity protection, and thus more equitable to human development.

1.2. - THE ROLE OF DESIGN

The position of design in the above situation is highly relevant, being clearly part of the equation in industrial production and economic growth, it could also be part of the solution. Therefore, designers have replied to the above problems, by creating a substantially large body of knowledge, tools and methodologies, in order to improve a products' sustainability.

'Design' according to Simon (1996) relates to the 'courses of action aimed at changing existing situations into preferred ones', the key word in that statement is 'change'. The differences between different types of designers lie in the sub-level categories of professions and their specific knowledge and skills, besides the type of problem defined, etc. (Schön 1983), but 'change' is the central element to all of them.

This description of design opens the perspective to realise that design, being a natural and intrinsically human activity, is impossible to be universally determined, neither would we want it to be. Design will always mean different things to different people depending on its context and history.

The design field offers multiple initiatives to empower sustainability, e.g. Okala Design Guide (White, St. Pierre et al. 2014), Natural Step (Step 2014), Total Beauty (Datschefski 2001), Biomimicry (Benyus 2002), Cradle to Cradle (PLI 2014), and many more. There are many coincident points within different perspectives, but Shedroff (2009) summarises it very clearly: "One serious problem for designers is that, even with a systems approach, there are few tools in existence that wrap these issues together. Instead, designers must learn to match together a series of disparate approaches, understandings, and frameworks in order to build a complete solution". This may create as a consequence that incorporating sustainability criteria into projects is dependant on personal awareness, skills and knowledge.

Designers are, by active association, co-responsible for the pressure on Earth's ecosystems, and up to 80% of the impact can be traced back to the early stages of the design process (EuropeanComission 2012). For designers, the main constraint might seem to be having access to knowledge of multiple and complex interconnected factors in an easy, simplified and digestible form, even before starting a project, and especially in those early stages of design. Added to this is the possibility to transcend the realm of products and explore creative solutions throughout the entire life cycle, giving designers the opportunity to propose entire new business and service models.

Therefore, effective and rapid access to information and reflection on concept generation during the early stages of design may reflect in significant improvements in environmental impact. As a result, it is recognised the high importance of early stages of design to improve products' sustainability.

1.3. - RESEARCH AIMS, OBJECTIVES AND QUESTIONS

Considering the discovery through the literature review of the relevance of integrating complex sustainability criteria in early stages of design, when it is more efficient to do so; and moreover, the lack of methodologies and tools to support designers in those early stages, drives this research to its aim:

To test if the delivery of sustainability related information through means of a novel computational "soft modelling" and life cycle visualisation tool is an appropriate form for the culture and working characteristics of designers at the early stages of design.

In the literature review the concept of 'soft modelling' will be introduced as possibly the most suitable for this purpose. Therefore, the next research questions are proposed:

Research Question: *How are the designers' working processes influenced or altered when sustainability-related information is presented in early stages of new product development, through means of an online "soft modelling" software?*

Sub questions:

RQ1: *Is "soft modelling" a meaningful way of presenting sustainability information to designers, at early stages of a new product development?*
RQ2: *As an eco-design tool, when is the software being used?*
RQ3: *As a way of identifying the progression of the design process, are the creation of sketches or any other external representation altered by the use of the tool?*
RQ4: *Did the presence of the "soft modelling" tool and its information, help designers envisage sustainable solutions?*
RQ5: *If RQ4 is positive, could it be argued that there was an increase in the speed of identifying sustainability factors?*

The specific objectives of this research are:

- To review the current literature in order to find the most relevant knowledge about sustainable design and what tools are most common, and if designers are actually using them or not. Furthermore, review the methods with which the design process can be captured and analysed in order to identify any influence from the tool.
- To create a tool, which presents such complex information specifically addressing the needs and working cultures of designers at early stages of design.
- To gather data from the designers' practice by first exposing them to the tool and explaining its aims and objectives, and then later perform a routine design task.

- To identify the key characteristics of the designers' working processes being altered or influenced by the presence of the tool, and the information that it delivers.
- To propose recommendations regarding the tool and how to apply it.

1.4. - LIMITATIONS OF THIS STUDY

In real-life conditions design projects rarely are related to sustainable design exclusively. Designers must deal with several complex issues, which they must ponder and prioritise by relevance, which in turn could be linked to many different reasons: economical, technical, political, etc. Therefore this study will consider sustainability issues with no particular emphasis, and will attempt to recreate as 'natural' characteristics in the tests as possible, whilst acknowledging the limitations in this fact.

The tool developed for this research could not contain all the characteristics and recommendations to assist designers at early stages of design found in the literature review. This was due to time and resources constrains of the research, which gave as a result that the first version of the tool was the one tested, and with no chance to iterate in the design process of the tool itself and improve it. Therefore, it is recognised that the tool is not yet fully fit for its purpose.

Research studies analysing designers in action are normally performed with students, this is due to the difficulty of finding volunteers among design professionals, which are normally very pressed by their commercial activities. In this research a strong effort has been made to include professional designers. It is acknowledged that in some cases the protocol was not followed as designed, due to lack of time or unexpected events (with the exception of one, all professional designers were tested at their work location).

The complex ill-structured nature of design problems, the limited time of this research and number of tests performed, as well as existing limited capacities for capturing the designers' thinking process, makes the findings of this research not viable to be generalised, larger samples and further testing will contribute to more robust results.

1.5 - CONTENTS OVERVIEW

This thesis is divided in nine chapters: introduction, literature review, analysis of research methods, 'soft modelling' tool development, description of investigation, data analysis, discussion of findings, contribution and final reflections on Trophec and soft modelling for early stages of design.

Literature review

The introduction of the literature review, chapter two, aims to set a framework about sustainability not as a fixed state, but rather as a process continuously changing, and discusses the characteristics and complexities of the factors that make it such. The main body of the literature review is dedicated first to present some of the actions the design profession has done to contribute to the protection of our environment, and the promotion of a more egalitarian economy and society; the methodologies, the tools and frameworks to support their work. How and when designers normally incorporate sustainability in their practice, and when it is more effective to do so. Due to their relevance for this research, several Eco-design tools are presented and briefly analysed.

At the end of chapter two a review of the design process is made in order to identify its components, and how this process deals with its intrinsic uncertainty and complexity. The phases this process has and what is developed in each one of them, the concepts of problem and solution space are studied and their relation to these phases. An important section in the analysis of the design process is how designers design, their cognitive processes and the internal and external representations of it, the notions of symbols, schemes, realm and relations are reviewed. Special attention is made to the importance of sketches, their transformations and its characteristics of ambiguity and density, and their relevance for creativity.

The literature review closes with a series of reflections and conclusions, and the identification of gaps in knowledge, which led this research to the creation of 'Trophec' a 'soft-modelling' tool for early stages of product design.

Analysis of research methods

In the analysis of research methods, chapter three, the principal methods to study the design process are analysed according to the aims and objectives of this research project: capturing designers' work through sketching (external non-verbal figural representations), and dialog (external verbal representations) through the think aloud method.

Furthermore other methods like concurrent and retrospective reports are discussed as important tools to widen our understanding of the designer's working process. All the previous elements are enclosed in a discussion regarding the need for a mixed methods approach; due to the characteristics of this research, where uncertainty on how and when the working processes could be affected, drives this project to use multiple data sources, and how all of them could be analysed through visualising the working processes. A review of the visualisation methods other researchers have created is also presented.

Chapter three closes with a discussion on the methods selected for this study and how they were applied in each investigating session; the insights gained in each one of them and the changes performed as well as the advantages of the online nature of the 'soft modelling' tool developed, which allowed the analysis of data from users outside the planned sessions.

Soft modelling tool development

In chapter four a review of the creation and characteristics of the tool 'Trophec' is presented. How the decision of developing it was reached as a consequence of the author's previous work, and the findings in the literature review. What variables, steps and operations sequence are proposed which the users must follow to achieve a full life cycle of a given product. The final outputs: the impact per production day and per product, as well as the infographics the software displays per each country selected in the cycle: biodiversity, child labour and slavery, Human Development Index, demographic factors like population, population growth, and lastly electric energy generation sources (coal, oil, gas, wind, etc.).

Description of investigation

In chapter five it is described the protocol followed in the tests performed in this project, what designers were asked to do, the activities, the sequence and the differences between control and test sets. The relevant task of selecting a design brief is commented and the selected brief explained.

This research had two main data sources, the first one is the data gathered from the test performed by designers, both students and professionals, in four sessions organised by the researcher (in total 60 students and 6 professionals were tested). The second type of data source comes from the online users of Trophec, each user can save unlimited life-cycles. A total of 200 cycles from 94 active users were downloaded and analysed (Trophec had registered more than 400 users when the data was downloaded).

Data analysis

In chapter six a detailed analysis of data is performed for each session, and for each set or professional designer; was also produced a flow chart visualising the different elements of the working process. This flow chart shows in chronological order the creation of sketches, if these sketches were linked between them, new concept creation, their lateral and vertical transformations, the duration in time for each single working sheet that was used, how far or close the designer felt to have reached a final idea (concurrent report), and for the video recorded sessions the verbalisations and the use of the computer (all participants had always access to a computer and Internet).

The online data is first analysed as aggregated data from all users, in order to identify general preferences, and for the users with more than one cycle to detect any possible trend or pattern in the tool's usage.

Lastly two analyses related to the tool were performed. The first relating to the time participants used the tool during the sessions, and the second on how the use of the tool could be connected to the final proposals of all participants.

Discussion of findings

In chapter seven an initial discussion about how sustainability for designers not only seems to be based on personal skills and awareness, but even more, if the design brief requested the inclusion of sustainability criteria, and acknowledged that the test being performed was about sustainability in design, this is rarely considered. Next, due to the changes in the test protocol, the discussion turns into the structuring of the design process and the inclusion of specific moments to use the tool, to inform and reflect. An important section highlights the reactions of professional designers when interviewed about sustainability in their practice, and the conclusions related to the online data and Trophec performance.

This section includes a highly relevant interview, which was performed outside the 'soft modelling' tool testing. Dr. Chris Sherwin, head of sustainability at Seymour Powell consultancy, provides an interesting perspective on how the design culture, in relation to sustainability, has moved very little in the last 14 years, putting this research in a bigger temporal context, which adds to the relevance of its findings and contributions.

Contributions

Chapter eight focuses in the overall conclusions and a summary of key findings and the contributions of this research project. It also covers the research's limitations and possible areas for future research.

Final reflections on Trophec and soft modelling

Chapter nine highlights the current limitations of the tool developed and the need of further development, and discusses if the soft modelling approach might be the right path to follow for future research.

Chapter 2 – SUSTAINABILITY AND DESIGN

2.1 – INTRODUCTION

This chapter will first provide a general introduction into the complexities that represent sustaining a process perennially in our physical environment, a process such as human development where design stands in a key role. From one perspective the natural structures and mechanics created through billions of years of evolution, and from another the human interventions and their disruption of those natural structures, which ultimately leads to the understating of the impossibility of continuing with certain human activities as they are performed now, and how design interleaves in it.

Subsequently, this chapter will present some of the work done in the design field regarding sustainability: important frameworks and approaches, tools and methods that support designers' work, and some of the problems the discipline still faces. Finally, the chapter will present an analysis of the design process, its main steps and components, and how these may relate to how sustainable design is carried out. This will highlight when it is more effective to incorporate sustainability criteria in new product development and the main deterrents for it to happen identified so far by researchers. By considering the previously mentioned, an important gap in research was detected, giving space for this research.

2.2 - THE COMPLEXITY OF WHAT IS SUSTAINABLE

A dictionary definition of the word 'sustainable' is: "able to be used without being completely used up or destroyed" and: "able to last or continue for a long time" (Merrian-Webster 2014). In order to reflect on the multiple factors of sustainability, it is necessary to start with the only two constants we can study through time and space that have been here always and will "continue for a long time".

According to the most accepted theory today, the total amount of matter and energy in the Universe has always been constant, since the big bang, 13.8 billion years ago (Peebles, Schramm et al. 1994). All phenomena has been just a constant change in state of that matter and energy, as there is no other 'place' to take from or to give to. Furthermore, Einstein proposed that energy and matter are exchangeable, his theories have now been proven right and are helping us in everyday activities (Cox and Forshaw 2010). Even human existence itself and the energy that moves our bodies are part of this ordinary constant change of state of matter and particle organisation (Malone and Dolter 2010), and energy is what makes it happen. Without it, there will be no movement, no heat, no light, nor life. According to Simon (1996) design is about “changing existing situations into preferred ones”, therefore if change is at the root of design, understanding the mechanics of energy and matter must be of interest too.

Some types of energy are stored in our planet itself, still part of its process of formation. The first to mention is the heat in the Earth’s core that is known as “geothermal” energy. The second type of stored energy Earth has is much more complex, yet part of the same process; living organisms are reservoirs of chemical energy. This is the decay of organic matter that was trapped and preserved inside the Earth’s crust, in particular conditions of heat and pressure, which are also forms of energy, transforming those compounds into even richer chemical reservoirs of energy. Today, we call these fossil fuels, which do not replenish by themselves or from any other input, therefore, are not renewable.

The sun’s energy travelling through space and hitting our planet is the only external input flow of energy to Earth. In figure 1.1 the complex nature of the sun’s energy flow in the Earth’s atmosphere is shown. Water heating up and cooling down is what makes ocean currents possible, thus heat coming from the sun being transformed into kinetic energy, and the same occurs with the air creating wind currents. As long as the sun shines, we will have this kinetic energy in the wind and oceans, therefore it is considered renewable.

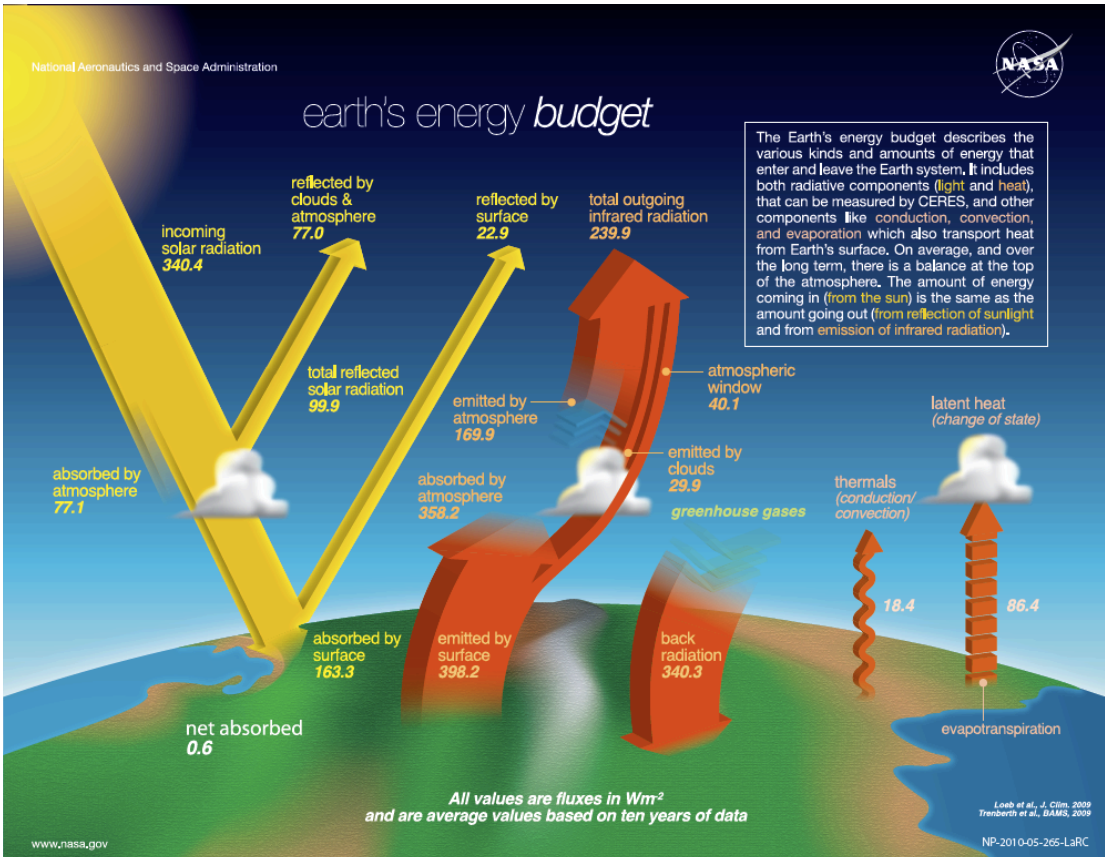


Fig. 1.1 Energy Budget (NASA 2014).

By using these types of energy, evolution has created a highly complex 'web of life' (Capra 1997), which is regulated by the principles of energy and matter exchange found in the laws of thermodynamics. We humans are, without doubt, part of that web and we are ruled by those laws. The web's complexity comes from the fact that all species and their environments are greatly interconnected and interdependent, which have grown exponentially creating even more complex dependencies that are almost impossible, for current human knowledge and capacity, to fully embrace them in the ephemeral decisions of everyday design work. As designers' actions inevitably disrupt those dependencies, the ultimate question is therefore: at what point could those disruptions become a danger for our own existence?

Society -the organisation of humans in groups- and its population growth, resource consumption, habitat transformation and fragmentation, energy production and consumption, are just some of the mechanisms (Barnosky, Hadly et al. 2012) that are profoundly disrupting the natural systems and shifting the biosphere into an unpredictable state. Designers, along with many other professionals, are active players in some of these processes.

The demand for energy and food is growing more rapidly every day, thus so is the disruption of the natural systems as a consequence. It was not until the industrial revolution, particularly in the 20th Century, that exponential growth revealed it's impact (Bartlett 2014) as the levels of energy requirement rocketed (Smil 2000). The discovery of fossil fuels in part was a catalyst; millions of years of energy storage have now been burnt, most of it to generate movement in transport and electricity for the machines that have transformed our environment. Improvements in human health and many other factors have also contributed to the current scenario, where exponential growth in the consumption of matter and energy has proven to be physically impossible (Daly 1992, Meadows, Randers et al. 2004, Heinberg 2007, Latouche 2009), and where economics, production systems and therefore design play a central role (Spangenberg 2001, McDonough and Braungart 2002, Jackson 2009).

If a long-term sustainable development is the objective, McDonough and Braungart (2001) put it quite simply: '*the conflict between industry and the environment is a design problem'*. In this sentence, the word 'design' takes a profound meaning; it not only relates to the profession, but to human activity, and to those ephemeral decisions of everyday living. Thus, the path for a sustainable development lies in the hands of not only designers, but everyone involved in 'designing' and changing our environment.

One clear example is the car industry, the largest of all industries, employing millions of people around the world, sustaining the livelihood of millions of families. The number of vehicles in the world surpassed one billion in 2012 (Tencer 2013). China alone has increased its roads by 27.5%, which represents half of the world's growth (Tencer 2013). According to the OECD (Organisation for Economic Co-operation and Development) there will be 2.5 billion vehicles in 2050, which will require a world oil production of at least 120 million barrels per day, an increase of 23% from today's needs (Tencer 2013). In monetary terms it is a highly profitable business, which we simply can't allow it to happen (Berners-Lee and Duncan 2013). The problem also becomes critical when considering the resources involved in manufacture, when in some cases 50,000 pounds of raw material are required to build a 3,000-pound vehicle (van Hattum 2006).

Transport all together represents 6.3% of global CO_2 emissions (Stern 2007). And now there is undeniable evidence of its impact on the Earth's atmosphere, and its anthropogenic origin (IPCC 2013). Nevertheless, Kingsley and Urry (2009) state that: 'It is very unlikely that everyone in the future will be travelling on foot and by bike, and especially not by public bus… and the individual flexibility, comfort and convenience the car provides is going to disappear'. Therefore the problem is also social; it is about ways of living and social innovation (Manzini 2007). This represents a completely new challenge for designers (Manzini 2009).

The ever increasing human demand of raw materials (McKinsey-Global-Institute 2011), and the global character of our economic system normally don't keep track of the complex supply chains that has produced, which obscures the impact this has on ecosystems, precluding the assignment of responsibilities. This is well known in the design field, and in following sections of this chapter, the methods and tools designers use to measure the impact of their decisions and assist them in designing better products will be presented. Alongside this, research will be presented regarding their lack of effectiveness and little change achieved so far.

Joseph Fiskel (2001) mentions in his work that 'what gets measured gets managed'. Nevertheless, as discussed earlier, natural and human systems are highly complex. Measuring the impact of designers' activities in natural systems has equally proven to be a great challenge. A good example of this complexity is the externalisation of costs, as many aspects of product manufacturing are being exported to developing countries like China. Despite local improvements, global statistics demonstrate that CO_2 emissions, loss of ecosystems and social inequality are still growing (Jackson 2009). Fiskel (2001), proposes the measurement of the economic performance by quantifying the hidden costs, estimation of uncertain future costs and cost and benefits of all stakeholders;

environmental performance by increasing shareholder value, has shown by Feldman, Soyka and Ameer (1997); and social performance by the social accountability for human rights, quality of life and equity. These three are subject of designers' influence through addressing the relation of resource consumption and value creation, including the economic, environmental and social aspects of the product, by systematically considering each stage in the product life cycle, and developing leading and lagging indicators of product performance.

One last crucial factor

The constant growth in resource consumption and its impact in ecosystems has been mentioned previously, but it has not yet been explored as to the reasons why mankind is pursuing what may clearly be a dangerous path. As it was discussed in the introduction of this document, improving human well-being is more an issue of equity, rather than growth.

For many centuries, agriculture was seen as centre of the economy, until the late 17th century when Britain shifted towards producers, consumers, value and utility of goods, and design started to shift from a craftsmanship work into a profession. This approach was later empowered by the beginnings of the industrial revolution (which in turn empowered the beginnings of design), where the basic factors of classical economics were born: land, labour and capital; the work of Adam Smith 'Wealth of Nations' in 1776 was key to this development.

Smith's 'invisible hand' stimulated economic growth by means of the efficiencies gained through the division of labour: the more has been produced and consumed, the more the economy grows, and so do the markets; giving way to the accumulation of capital by savings and the opportunity for profit, it is the so called 'Smithian growth' (Kishtainy, Abbot et al. 2012). Slowly, the work of many designers became one key resource to increase consumption and profit.

In the view of classical economics, consumption is the sole end and purpose of all production, and labour (firstly intended as human physical work) adds value to land (resources) through capital (means of production like machinery). Simonde de Sismondi in 1819 suggested that "*Universal competition, or the effort to always produce more, and always at a lower price… has been a dangerous system"* (Kishtainy, Abbot et al. 2012).

For classical economists natural resources are considered free, and the awareness of pollution coming from its transformation was present since early times. Nevertheless, the focus on economic growth and the constant search for profits, added to the great complexity of human behaviour in today's economic system, have presented arguments that confront economists and governments' actions (Kishtainy, Abbot et al. 2012).

When Nobel laureate Paul Krugman (2008) analysed the reasons for the constant increases in raw materials prices (McKinsey-Global-Institute 2011), he arrived at powerful conclusions. He proposed three possible reasons: simple speculation; a shortage that eventually will come to an end; or simply we are running out of planet to exploit, the ever-growing world economy vs. finite planet, the resources are harder to find and thus becoming more expensive, 'the good times may have just stopped rolling' (Krugman 2008).

Stiglitz (2010) went even further by saying that we have to change capitalism because it has been proven wrong. It is not just a matter of a few flawed individuals, or minor technical problems, or the tweaking a few policies; rather he said that rugged individualism, market fundamentalism, rampant materialism, standards of living having to fall, are all emblematic systemic failures, which reflect deeper social problems (Stiglitz 2010). "Growth is more of the same stuff, development is the same amount of better stuff" (Daly 1992).

This ideas have made influential designers such as Ezio Manzini (2007) to propose a change of society's search for fulfilment from a "product based" to a "context based". Jackson (2009) writes about shifting our "novelty driven" society into a "flourishing" one. Ideas that are driving important areas of design practice and research like the DESIS network (DESIS 2015).

The statement "*The conflict between industry and the environment is a design problem"* (McDonough and Braungart (2001) could now, after this chapter section, be proposed as 'the conflict between mankind and the environment is a design problem', because design, as a human intrinsic activity has created its systems, and modified the context so heavily that for first time in human history, its survival is in peril (Deutsch 2005). And by this, it's not intended to infer that designers have the responsibility or capacity to solve human sustainability problems, but rather to acknowledge its responsibilities. To make the appropriate changes to its practice and see the potential of design thinking, and the knowledge about it created so far, as a relevant method to assist in the search for a sustainable development.

With a basic understating of the natural processes occurring on Earth, it can be argued that sustainability could better understood as moving along these processes, and represents our 'ability' to 'sustain' our existence through time under such conditions.

Sustainability is not a fixed state to achieve, but rather our capacity to evolve and adapt together with the constantly changing natural systems. All of the previous discussion recognises the multi-dimensionality of sustainable development – therefore, its solutions must be partly out of designers' hands, but under the same principle, out of the hands of managers, marketing, etc. too. Consequently, a holistic integrative approach is urgently needed.

2.3 – DESIGN CONTRIBUTION TO SUSTAINABILITY

The act of designing as a meta-definition relates to the "courses of action aimed at changing existing situations into preferred ones" (Simon 1996). The intrinsic requirements and consequences of change, its basic origin in matter exchange, and the energy required, have been discussed in the previous section. Humans, in order to improve their well-being have brought about a great number of changes to their context. Designers, and for the purposes of this research, particularly industrial designers (sometimes referred to as product designers), have been active players in these changes and improvements.

The exponential economic growth fed by product consumption, as discussed previously, has created dangerous pressures on the ecological systems that sustain not only human life, but also all other species. Acknowledging its responsibilities, the professional field of design has been very active and the body of knowledge generated in relation to design and sustainability is extremely vast.

As an example, the term 'ecodesign' displays 511,000 results in main Google search engine, and 12,000 in Google Scholar[1]. Nevertheless, if we look at Google Trends, the number of searches for that term since 2004 has seen a surprisingly slow fall. Slightly faster falling trends can be found with the term 'sustainable design' figure 2.2, but this time with 1,890,000 results in main Google search engine and 30,000 in Google Scholar[1]. The reasons of this apparent decline in interest might be related to a probable sense of powerlessness over a large and multidimensional problem.

[1] Consultation made by the author the 4th February 2014

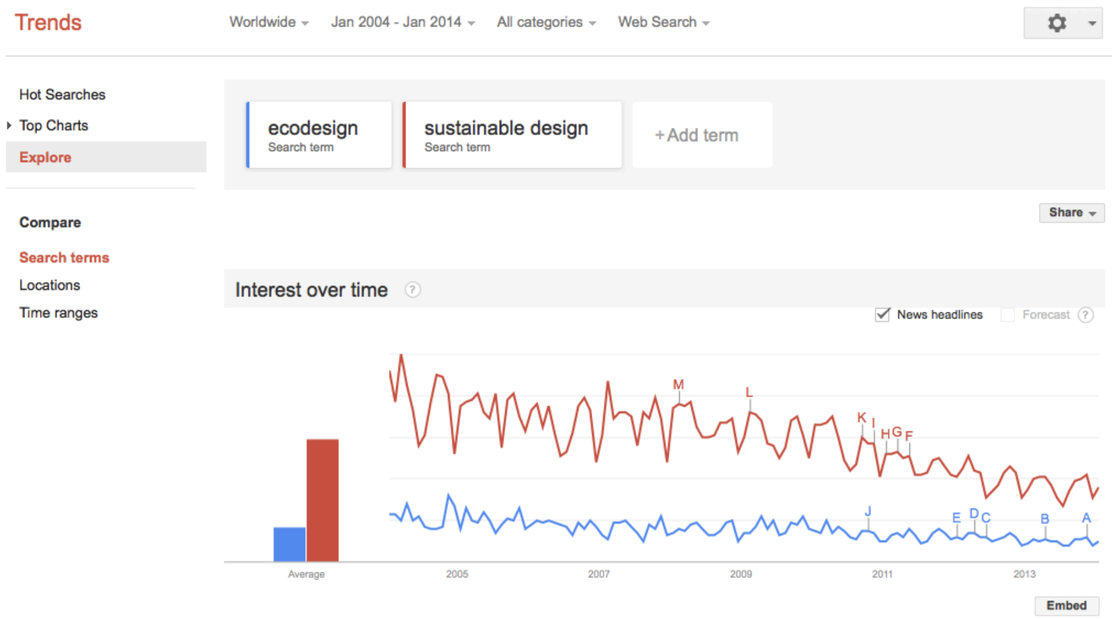


Fig. 2.2 Google Trends' results for 'ecodesign' and 'sustainable design' (source: Google Trends).

As one possible starting point, the clarification of different, widely used terms is reviewed. By performing a quick literature review relating to sustainable design the following terms emerge: ecodesign, sustainable design, environmental design, design for environment, among many others. Tischner and Charter (2001) presented a compelling organisation of three of these terms, which may encompass all others, figure 2.3.

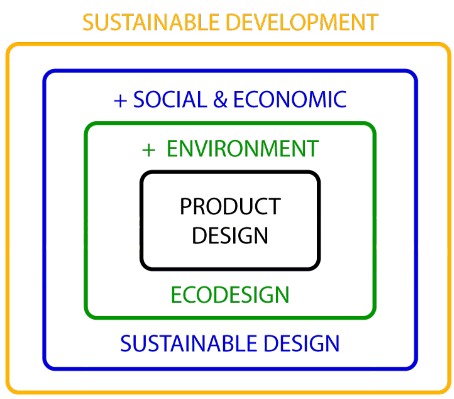


Fig. 2.3 What is Sustainable Product Design? Adapted from: (Tischner and Charter 2001).

In their chart, they place Product Design at the centre, as a ground base of all activity that has been taking place since the profession's beginnings. If considerations relating exclusively to the environment are added, such as materials source impact in water or air pollution, etc. it is then referred to as Eco-design. Above this level, if issues related to a social and economic character are added, it is then called Sustainable Design. Lastly, above all in a different layer, there is Sustainable Development, as a general human objective, the interconnection point with all the other professions.

Ecology, from the Greek οίκος, "house"; λογική, "study of" is evidently the origin of Eco-design. As stated previously, it refers exclusively to the consideration of environmental issues in the design process. Nevertheless, it may present certain confusion, and some designers may mix Eco-design and Sustainable Design indiscriminately. This confusion may arise from the hierarchical characteristics of systems, which contains subsystems in an infinite number of layers; all human systems are part of a subsystem dependant ultimately on Earth's ecosystems, as has been discussed previously. Vezzoli and Manzini (2008) see Eco-design as the connection between what is 'technologically possible with the ecologically necessary', clearly acknowledging the limits of our supporting ecosystems.

Sustainable design on the other hand, is defined by Thorpe (2007) as: "theories and practices for design that cultivate ecological, economic and cultural conditions that will support human well-being indefinitely". Both definitions support Tischner and Charter's organisation (Tischner and Charter 2001).

In the section 2.2 (p.30), the multiple and complex factors of sustainability were discussed, and more importantly, it was described not as a final fixed state to achieve, but rather a constantly evolving process to maintain. Sustainable design represents an initiative to change the order of things, and is by principle opposed to those who profit by the current structures, or those who see in it not a 'radical enough' concept, and both could be in any environmental, social or economic dimension (Spangenberg 2001).

Therefore, some interrogatives might be: What is a good design? What represents a good design in this change of the order of things?

In the contemporary field of design, a highly appreciated example of 'good design' comes from German designer Dieter Rams, who stated in 1975 "the curtain of time is falling upon an era where unimaginative design was able to flourish under unimaginative manufacturing conditions for unimaginative consumption" (Burkhardt and Franksen 1980). Rams proposed ten 'good design' principles, according to him a good design must be: innovative; make a product useful; aesthetic; make a product understandable; unobtrusive; honest; long-lasting; thorough down to the last detail; environmentally friendly and as little design as possible.

Nevertheless, Ram's principles are too broad for practical applicability. For example, 'environmentally friendly' could include the selection of recyclable materials as the understanding of the recyclability of products, but the latter also as intrinsically necessary to close the cycle, which may not be the designer's decision alone; it belongs to a higher ‘systems’ perspective where business model design must be also included (Baynes 2001). After all, design briefs are normally written by senior management making strategic decisions (Sherwin 2000). Recent evidence (Deutz, McGuire et al. 2013) supports the fact that designers are not performing environmentally good practice for two main causes: designers’ understanding of environmental issues, and the influence of constrains that are out of the designer’s control such as legal, economic and supply chain issues. Both designers’ external and internal constrains will be further explored in subsequent sections of this document.

2.4 - PRINCIPAL FRAMEWORKS

Several design practitioners and researchers have proposed general frameworks that support the notion of good design and also propose a sustainability point of view. A detailed analysis of each one represents an endeavour beyond the goals and scope of this research. Nevertheless, a brief description and analysis of some frequently cited in literature is presented below.

NATURAL STEP

This framework was first proposed by Dr. Karl-Henrik Robèrt in the 1990s (Step 2014), It proposes four fundamental conditions based on systemic principles on which the biosphere functions. Principle one: the systematic increase of concentrations in the atmosphere of substances extracted from the Earth's crust (for example, heavy metals and fossil fuels) must be eliminated. Principle two: the systematic increase of concentrations in the atmosphere of substances produced by society (for example, plastics, dioxins, PCBs and DDT) must be eliminated. Principle three: the systematic physical degradation of nature and natural processes (for example, over harvesting forests, destroying habitat and overfishing) must be eliminated. Principle four: conditions that systematically undermine people’s capacity to meet their basic human needs (for example, unsafe working conditions and not enough pay to live on) must be eliminated. All principles can potentially be applied by designers e.g. in the simple choice of materials or decisions about the concept’s embodiment.

It focuses attention on the sources of the most important impacts, creating a general picture in which general progress could be achieved to diminishing pressure on the biosphere. It proposes a graphical way of representing this through the Natural Step Funnel (Step 2014) figure 2.4, in which the diminishing capacity of natural systems is showed, as well as the increasing pressure of societies’ demand. The more the funnel closes the less chance we have of reaching sustainable development.

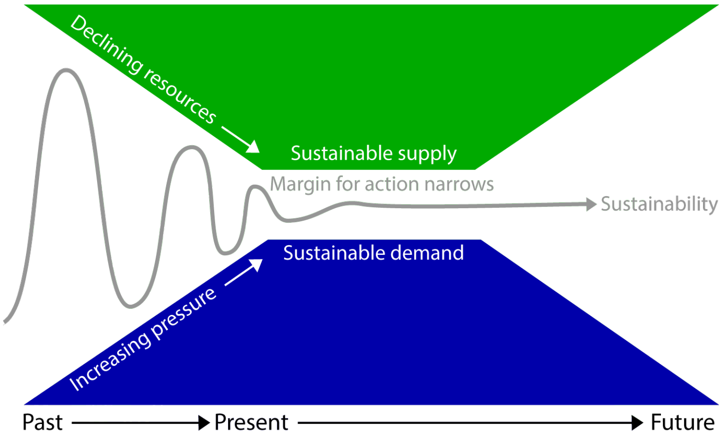


Fig. 2.4 Natural Step Funnel the author after: (Step 2014)

Criticism of this approach normally lies in it's broadness, subjectivity and lack of formal techniques for development (Shedroff 2009). Designers don't know yet how to apply these very general concepts into very specific daily routine tasks, and at the speed that product development unfolds in a professional context.

CRADLE TO CRADLE

Cradle to Cradle was first proposed by Walter Stahel in the 1980s (PLI 2014), and later made popular by William McDonough (McDonough and Braungart 2002). It is also referred to as one model of eco-efficiency; its focus is in the cyclic natural characteristics of waste and food. A certification is available to those products that fulfil the elimination of hazardous (toxic) materials, achieves a state of 'Waste equals food' (restating the definition of waste), the use of solar energy and the use of 'upcyclable' materials.

Regarding this last point, Cradle to Cradle differentiates 'biological' from 'technical' materials; the latter understood as made by humans, therefore not found in nature, and should always be kept in a cycle of 'technical nutrients'. Similarly with biological, the combining of technical and biological produces 'monstrous hybrids' and should be avoided, since they cannot be reintegrated easily into any of the two cycles. 'Upcyclable' refers to the capacity to reintegrate both of these materials into their own cycle indefinitely, without compromising its chemical and structural characteristics.

Critics point to the failure to cover financial or social issues, and the failure to make explicit the whole life cycle (Shedroff 2009). The return to the 'natural' or 'technical' cycles is key, but just like before, designers don't have yet clear and fast access to the understanding of what these concepts mean to daily routine tasks.

Natural Capitalism

Natural Capitalism is a framework developed by Hawken et al. (1999). It is often referred to as one model for eco-efficiency and defines four types of capital: Human capital; the value of work and ideas, by individuals and society. Natural capital: materials and energy (physical), processes and effectives, ecosystem services and resilience due to biodiversity. Financial capital: money in its many forms; cash, credit, stocks, bonds, etc. Manufactured capital: all materials and energy created through human intervention and which are not found in nature, including intellectual property.

It recognises the value of ecosystems services and requests four 'shifts': Radical resource productivity: which authors say can be done immediately with current technology. Ecological redesign: moving our perspectives and processes towards ones more inspired in biological organisms. Service and flow economics: changing the focus from products to services, and from objects to outcomes. Investing in natural capital: in order to grow robustness and resilience in the world.

Criticism of this approach is mainly based on its 'Cradle to Grave' character (Shedroff 2009); it is essential to recognise that eco-efficiency simply will not work in the long-term (McDonough and Braungart 2001).

Biomimicry

The name 'Biomimicry' itself explains the approach; it takes inspiration from natural processes and imitates them for human purposes. Proposed by Janine Benyus (2002) as an inspirational approach, it is based on the analysis of how nature is capable of building, sustaining and reintegrating all living things into cycles. It proposes several principles of nature that may serve as guides e.g. power of shape, colour without pigments, green chemistry, sensing and responding, cyclic solutions, diverse solutions among others.

It then provides a 'design spiral' which guides the designers through five different steps that are repeated as necessary: distil the design function; translate to biology; discover natural models; emulate nature's strategies and evaluate your design against life's principles.

Critics of Biomimicry point to the difficulty in maintaining objectivity, the requirement for biology expertise, and the failure to address directly social or economic issues, due to their human nature (Shedroff 2009).

TOTAL BEAUTY

Proposed by Edwin Datschefski (2001), Total Beauty identified five areas to analyse the sustainability of products, redefining what is 'beautiful'. Cyclic: natural or technological cycle, closed loop. Solar: all energy from renewable resources. Efficient: less material and energy. Safe: no hazardous materials, all releases are safe food for other systems. Social: no work exploitation and human rights.

It is a quantitative approach through a system of points, which calculates the total impact of products and services. "Beauty… isn't valuable for its accuracy so much as the general impression… Often, this is what designers need to know most, especially during concept and prototype phases" (Shedroff 2009).

SUSTAINABILITY HELIX

The Sustainability Helix is a framework created by the authors of Natural Capitalism (NCS 2014) with a management approach, it is centred on an interest in the organisation, and the activity to progress towards sustainability standards. It contains five stages in which to monitor progress: 0 unsustainable, 1 exploration, 2 experimentation, 3 leadership, 4 restoration.

This framework describes measures in order to assess an organisation's position, and provides the strategies to achieve previously stated goals. This is done under six categories of operations and management within a company: governance and management; operations and facilities; design and process innovation; human resources and corporate culture; marketing and communications; and partnerships and stakeholders engagement. The nature of this framework makes it more relevant in a corporate and management level rather than a design one.

LIVING PRINCIPLES

It is a framework aiming to create a 'positive cultural change' (Living-Principles 2014) and guides the designer through four streams: environment; people; economy and culture.

It declares a special interest for being actionable by designers, business leaders and educators. It provides a 'roadmap' with a series of questions to help users develop a holistic view to sustainable solutions. Solutions can range from technical ones like behaviour, impact, durability, disassembly, waste and 'closing the loop', to more strategic ones such as visions, meanings, benefit, diversity, etc.

Life Cycle Assessment

The Life Cycle Assessment (sometime also referred to as Analysis) is probably the method most used to determine the impact of a product on the environment. According to the European Union Integrated Product Policy (EuropeanComission 2003): “LCA is merely a decision-supporting tool, rather than a decision-making tool, since it has a specific focus. It particularly tends to exclude economic and social impacts, as well as the consideration of more local environmental issues. It is therefore necessary to use it in conjunction with other tools to assist in identifying areas of potential improvement”.

LCA is a quantitative “technique to assess the environmental aspects and potential impacts associated with a product, process or service” EPA (2006). It does this by compiling an inventory of the energy and material inputs, as well as environmental releases, evaluating their potential environmental impacts and interpreting the results in order to make more informed decisions. It has four different phases: goal and scope definition; life cycle inventory; life cycle impact assessment and interpretation. It is precisely in this last phase where some controversies may arise; due to the great amount and complexity of data involved, the final interpretation can be biased and prove difficult to decipher (Kim, Yang et al. 2012).

In order to perform a full LCA, special training and knowledge is needed, and there are a growing number of computational tools that help in the process. These tools are somewhat expensive due to the need for large and specialised data sets in order to perform the calculations.

As well as being expensive, LCA’s are also time consuming, do not usually address social issues, and the necessary data is sometimes non-existent or only accessible through specialised databases at very high costs; not adequate for design and prototyping stages (Shedroff 2009).

The frameworks mentioned above are by no means the only ones proposed; they are just a sample of the most often used and referenced. It is nevertheless clear that whilst there is a diversity of approaches, there are similarities, especially in the search of basic rules, overall principles, and in some cases, the simplicity behind the complexity.

2.5 - SUSTAINABILITY IN DESIGN RESEARCH

Further work has been done to try to establish more detailed applicable guidelines for use within these frameworks. One of the first and precursor of many subsequent frameworks is the ‘Seven Eco-design Steps’ (Brezet and van Hemel 1997) produced for the United Nations Environmental Program: organising an Eco-design project; selecting a product;

establishing the design strategy; generating and selecting ideas; detailing the concept; communicating and launching the product and establishing follow-up activities.

In their work they identified a series of internal drivers with a business perspective for Eco-design: manager's sense of responsibility; need for increased product quality; need for better product and company image; need to reduce costs; need for innovative power and need to increase personnel motivation. They also found external drivers such as technological innovations, legislation and regulations, market demands, social responsibility towards the environment, competitors setting the trend or follow and trade organisation cooperation or competition.

This work gave a wide perspective for design practitioners for a daily, operative work with a necessary business ground base. Furthermore, Brezel and van Hemel (1997) proposed a scale for the level of intervention depending on their sustainability impact, in incremental order: product improvement (lower impact); product redesign; function innovation and system Innovation (higher impact).

Thackara (2005) reached similar conclusions and describe them as: incremental improvements; redesign of products and services; products, services and systems that replace old models and redesign of whole systems.

Which Vezzoli and Manizini (2008) propose as: environmental redesign of existing systems; design new products and systems; designing new production-consumption systems and creating new scenarios for sustainable lifestyle.

Referring to an ideal of sustainability, they concluded that: "no partial modification, no incremental innovation of employed technologies, no re-design of existing systems can really bring us there" (Vezzoli and Manzini 2008). Their inclusion of 'lifestyle' as a sustainability concept comes with the notion of not obliging nor convincing the user, but simply offering better and more meaningful solutions, and that these are the main limits and opportunities for designers. Good design relates in this way to the resulting enabling combination of products, services and user participation.

This combination is expressed by some as Product-Service-Systems (PSS) strategies, which deals with product life cycle as well as the user's behaviour, and it is understood as a set of symbiotic and complementary processes, products and services forming a unique solution (Vezzoli and Manzini 2008). PSS, or the related field of Service Design, are wide fields of study, which the researcher acknowledges as highly relevant, but not the focus of this research. Nevertheless, the reorientation from product to service is seen as an interesting opportunity to achieve the dematerialisation OECD (2002), and UNEP (2011) have been calling for, in order to sell performance instead of selling products (Stahel 2001). For designers, this means considering issues often outside of their boundaries, and will very likely require the participation from other areas within the business (Sherwin 2000, Bhamra and Lofthouse 2007).

The related features of PSS, as a sustainable product design strategy, in which this research is interested, are the mentioned symbiotic and complementary processes identifiable within the product life cycle. This cycle is commonly organised in five main steps (Brezet and van Hemel 1997, Wimmer and Züst 2001, Vezzoli and Manzini 2008): raw material extraction; manufacturing; distribution; usage and disposal.

The number of variables and interconnections that must be considered within each step is overwhelmingly large, and some are of such complexity that they go beyond the designer's capacity and interest. Johansson (2002) identified six factors for integration of eco-design in product development:

- Management commitment and support; clear environmental goals, not only consider operational dimension but also strategic, included within a company's technology strategy.
- Customer relationships; customer focused and customers training in environmental issues.
- Close supplier relationships.
- Development process; environmental issues considered at the very beginning of the product development process, company-specific environmental design principles, performed in cross-functional teams, support tools are used
- Competence, education and training are provided; environmental specialist supports development activities, and examples of good design solutions are used.
- Motivation, new mindset; individuals encouraged to take an active part in the integration of eco-design.

The Design field has created a large amount of guidelines, checklists and analytical eco-design tools (Tischner 2001, Baumann, Boons et al. 2002, Pigosso, McAloone et al. 2014) to help designers deal with this complexity. The researcher has performed a review of some of them, which will be presented in the next section of this chapter. Nevertheless, before reaching that point, it is highly relevant to mention that this literature review has found evidence of a mismatch in relation to the characteristics of those tools, the characteristics of the product development stages, and the culture and cognitive processes of designers in each one of those stages, which is central to this research and that will be explored in detail in subsequent section of this chapter.

The importance of the early stages of new product development

Section 2.7 (p.86) will describe in greater detail the 'design process'; the steps designers follow in order to provide a solution for a specific design problem, and within it what would be considered 'early stages'. Nevertheless, in this section the term 'new product development' is introduced as a broader perspective in the creation of new products, which includes activities previous and posterior to the intervention of designers.

Vezzoli and Manzini (2008) identified the efficiency of integrating environmental requirements in the different stages of product development, and the applicability of one of the most widely mentioned tool for product development: Life Cycle Assessment (LCA). Figure 2.5 shows this relationship.

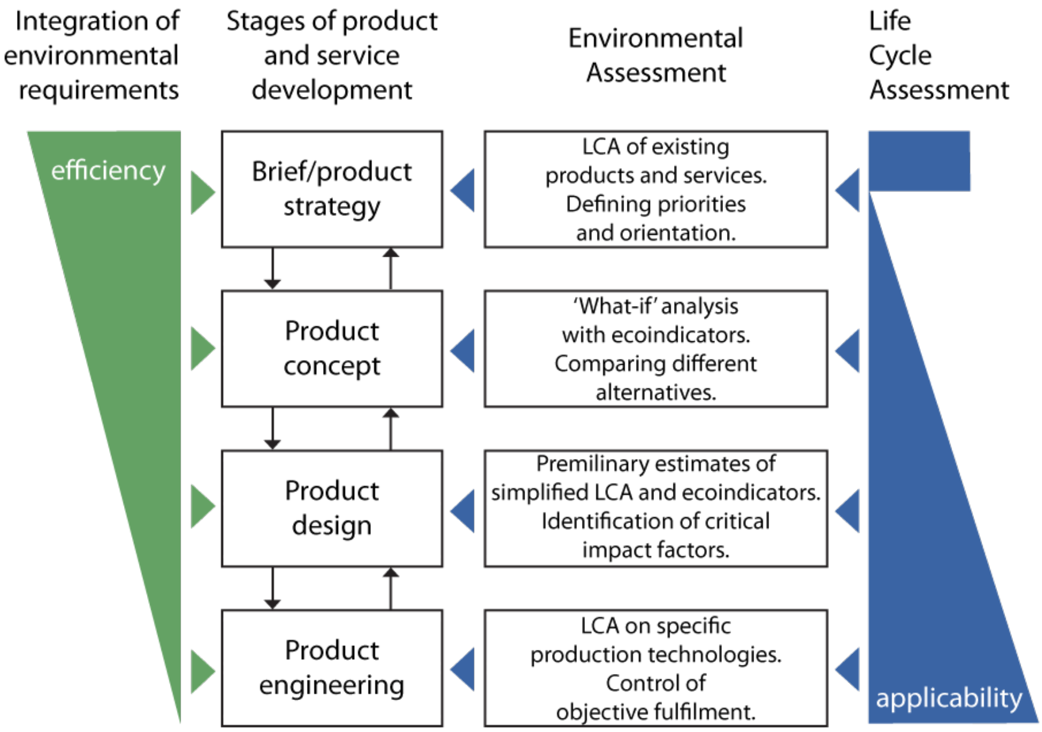


Fig. 2.5 Efficiency and applicability LCA (Vezzoli and Manzini 2008).

The efficiency of integrating environmental requirements is higher at early stages (Matzke, Corky Chew et al. 1998, Bhamra, Evans et al. 1999, Ritzen 2000, Sherwin 2000, Lindahl 2005) when the problem is first stated (sometimes in the form of a brief), and the product strategy or specification is defined (issue regularly and intrinsically multidisciplinary). This is the point where the information to solve it, if it is not already available, must also be acquired. These early stages are highly relevant because, as will be explained later in this chapter, the way the initial stage of a design problem is defined is crucial to the development of the entire process.

This efficiency then diminishes along the process due to the ‘moves’ (Schön 1983) taken by designers and other stakeholders, and the commitments that come along (Goel and Pirolli 1989), until the product finally reaches the market.

LCA, as has been described previously, is labour-intensive, normally requires special training and knowledge, and is therefore often beyond the financial and human capacities of many companies. Vezzoli and Manzini (2008) show clearly the lack of support in early stages of product development to integrate environmental requirements and the relevance of doing it precisely at this stage when it is more effective. This is further supported by the European Commission (2012), which stated through their Enterprise and Industry Department: “more than 80% of environmental impact of a product is determined at the design stage”. Similarly, Fabrycky (1987) found that over 70% of the final product is directly influenced in design stages. These findings have also been discussed by other researchers (Andreasen and Hein 1987, Burall 1996, McAloone and Evans 1997).

There is evidence of a lack of investigation in creative approaches at early stages and the few supporting eco-design tools specifically developed for it (Jones 2003). Sherwin (2000) takes a further step and concludes that eco-design is not even connected to design itself at all; it has normally been restricted to technical dimensions. Relevant research is presented below identifying the inappropriateness of some current eco-design tools for early stages and why designers are not using them.

Vallet et al. (2013) tested three different eco-design tools: Simapro, Ecofaire and Ecodesign Pilot, which the authors selected as representatives of the eco-design tool classification categories proposed by Knight and Jenkins (2009). These tools were tested by professional practitioners in a 1.5-hour protocol, which required the redesign of different products. 74% of subjects declared having previous knowledge of LCA use. The researchers used the next design phases to identify the subjects’ focus of tool application:

Problem: Goal (G), Initial Assessment (EI), and Strategy (St).
Solution: Solutions (So), Assessment of Solutions (Es), Decision (D), and Control (C).

Figure 2.6 presents the areas where participants focus the use of the tool.

Fig. 2.6 Tool usage along design phases (Vallet, Eynard et al. 2013).

These findings indicate the lack of relevance of these tools at early stages of design, with the authors declaring that environmental assessment and strategy definition as more influenced by expertise than the use of tools. This in turn may invoke fixation and a predetermined mental set (Sternberg 2003), probably caused by their experience (Purcell and Gero 2006) in the form of a 'pre-analytic vision' (Schumpeter 1954). Another probable cause for fixation might be related to the type of 'external stimulus' these tools represent to designers, and may not reply adequately in the level of abstraction and transformation found by Goldschmidt (2011). Later they identified the strategies used by participants according to Brezet and van Hemmel's (1997) classification, table 2.1.

	low impact material	material use	production techinques	distribution system	impact in use	life time	end of life
Simapro		x x			x	x	
Pilot		x			x x x x	x	
Faire		x x			x	x	x

Table 2.1 Strategies used by participants (Vallet, Eynard et al. 2013).

Adding to this, the focus shown here is limited in the entire life cycle, which may represent an inhibitor for the previously mentioned need of symbiotic and complementary processes. Lastly, the authors identified the type of design approaches according to Brezet and van Hemmel's (1997) scale, table 2.2.

	Simapro	Faire	Pilot
product improvement	4	5	1
product redesign	5	3	6
function innovation	0	0	3
system innovation	0	0	0
total	9	8	10

Table 2.2 Design approaches (Vallet, Eynard et al. 2013).

Once more the focus in low leverage approaches is shown. Therefore, the need for supporting tools that allow designers to move beyond the realm of products, and explore the possibilities of systemic change, incremental innovation and eco-efficiency will never be enough (McDonough and Braungart 2001). Finally the authors state: “the basic culture of designers does not allow them to know which lever is really efficient for environment improvement… new support tools to train designers with strategy definition should be investigated” (Vallet, Eynard et al. 2013).

The possibility of fixation in relation to environmental information as a deterrent for creativity, as well as the level of detail of this information, has also been studied (Collado-Ruiz and Ostad-Ahmad-Ghorabi 2010). Through the direct opinion of experts, numerical analysis and self-judgement, the researchers assessed more than 60 categories of methods, some with tool implementation.

Their first findings were the barriers for the internalisation of principles, barriers which inhibit most of the companies from applying any eco-design method due to complexity of implementation, need for specific training and the scope of solutions proposed. Specifically, the researchers state that the design community does not use them because they are time consuming and difficult to fit in the product development process, they require much information not available in initial stages, later information is available but LCA is no longer useful, complex modelling is not coherent with models used during design, they require special training, there is always some level of uncertainty

The most differentiating factor was a high detail in the information, because it does create fixation and diminishes creativity. Therefore they conclude: ‘information must be available, but fixation avoided’. Finally they define ‘soft information’ as the most appropriate for designers (Collado-Ruiz and Ostad-Ahmad-Ghorabi 2010). This particular proposition was of high relevance for this research project, which will be discussed further down this chapter.

Lastly Ostad et al. (2011) surveyed 11 design experts on their requirements for eco-design tools in 4 key aspects: information, motivation, multidisciplinary cooperation and creative environments.

Their findings can be summarised as follows: the main driver is environmental concern and the main deterrent is additional workload. For designers, motivation is more important than cooperation and information, but they saw these last characteristics as most needed for successful integration of these tools. Incompatibility of tools with the product development process is a reason for not using them.

Among other things the participants declared that eco-design is an additional process to the general design conception. The researchers therefore recommend: provide information as necessary in the design process, avoid excessive information and data flow, clearly show how design activities influence the sustainability performance of the product, allow information sharing between different departments, avoid excessive involvement of designers with the tool and assist the engineer designer in all design phases.

More tool characteristics have been identified; Lofthouse (2006) found in an 18-months long research project, that eco-design tools fail because they are not aiming for design. Rather they guide strategic management or existing product's retrospective analysis. She proposed five ideal characteristics: holistic tools, a combination of: guidelines, education and information, well considered content, appropriate presentation and easy access. And provides a website applying her concepts: www.informationinspiration.org.uk

Moreover, Bovea and Perez (2012) found that although the diversity of tools for integrating environmental aspects in new product development is wide, in real-life scenarios they are scarcely implemented, and they recommend three main characteristics for new tools, one: early integration of environmental aspects into the product design and development process, two: life cycle approach: how the product affects in its different stages, three: multi-criteria approach.

Other researches have explored in higher detail why designers don't engage with eco-design tools. Particularly interesting is the PhD thesis of Stevenson (2013). In it he first defines 'Responsible Design' to what in this document has been described as 'Sustainable Design', meaning the incorporation of not only the environmental considerations, but also de economic and social aspects in the entire life cycle of the product. He then sets to investigate through a series of interviews with experienced designers, the influencing factors on design consultants for the adoption of responsible design and what determines it.

He identified six areas, each with multiple and complex issues, these main areas are, one: the knowledge and understanding of how to address responsible design goals, two: consultant's motivations, three: consultant's capabilities, four: the opportunity available in terms of project priorities or project constrains, five: the level of influence the consultant has over the client and six: what is implemented in terms of manufacturing vendors or client's capabilities (Stevenson 2013). The first three areas are interconnected and are relevant for this research because are the ones that directly influence the designer's decision to use the tool or not, thus indicating some of the ideal characteristics figure 2.7.

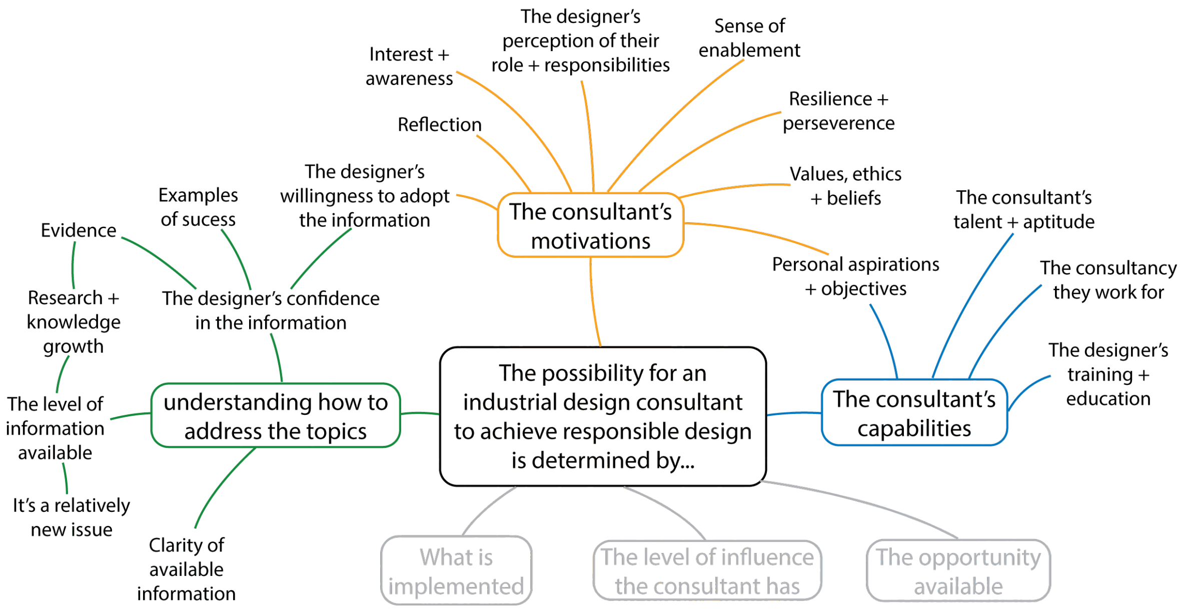


Fig.2.7 System of determining factors highlighting the three related to designers and the possible influences to use or not an Eco-design tool. After: Stevenson 2013

In the interviews Stevenson (2013) received specific comments related to the eco-design tools designers have available, which are similar things to what has been exposed here previously: designers want tools that are efficient in terms of less complexity or even overbearing, appropriate to the way designers work, one of them saying that he "rather have a 'ready reckoner' over a tool that can provide more accuracy but with greater effort', which aligns with other researcher's findings like Shedroff's (2009) when he talks about Total Beauty: 'isn't valuable for its accuracy so much as the general impression… Often, this is what designers need to know most, especially during concept and prototype phases'.

Nevertheless, Stevenson's contributions are enlightening, he describes a great number of complex factors deterring designers from engaging in responsible design, and which in many cases lie beyond designers' capacities and realm of action. He finalises describing the requirements to achieve responsible design commercially figure 2.8.

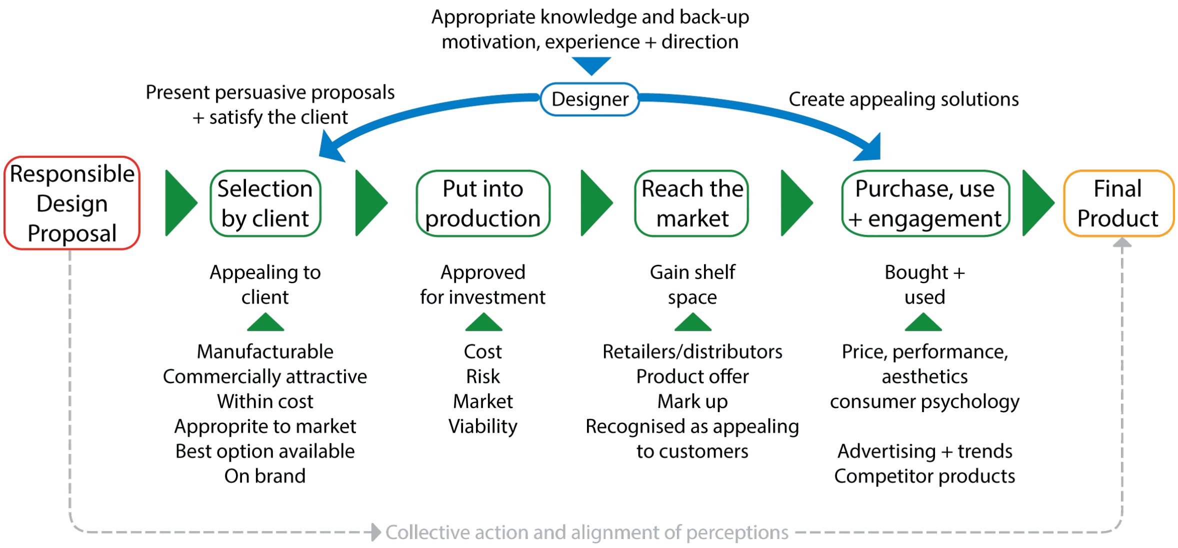


Fig 2.8 Requirement to achieve responsible design commercially. After: Stevenson 2013

Under the same theme, Lee-Mortimer and Short (2009) identified too some of the factors deterring designers to use eco-design tools, such as requiring too much time and specialised knowledge, that tools are too focused in the environmental and do not sit well within design process, among others. They also surveyed 66 companies in the UK, which had previously declared undertaking product development. As a result of this exercise they found what they called a "design paradox", this is that eco-design tools only become feasible when certain level of knowledge about the design is generated, and it is precisely when there is very little understanding about the product being developed when it is more efficient to integrate environmental considerations. To this issue they turn to analyse the involvement of marketing and management, and the process of product specification, they discovered that specifications are "roughly sketched" by marketing and/or management, and then passed on to designers, which they keep on defining while solving the design.

They propose that design for sustainability should start at the formulation of product specification integrating all areas of the company, and that eco-design tools should integrate better with it; this based on the discovery that large companies have more formal design processes and are able to integrate better sustainability considerations, which is not the case of SMEs, that many have no established processes at all. They concluded that the deep root lies in a company's culture of product development process and practice, rather than just the tools. More recently the same researchers (Short, Lee-Mortimer et al. 2012) replicated the experiment, this time with Swedish companies and found no significant difference.

Similarly Boks (2006) reached the conclusion that management and organisation seem to be more important than the tools, which alone are not sufficient condition to successfully integrate environmental considerations in business operations. He calls for paying more attention to what he calls the "soft side of eco-design", that is a variety of sociological, psychological, emotional and maybe even intangible factors, which a company or even on department level faces, and are obstacles for the integration of environmental considerations. In his research involving the electronic industry in Asia, Boks (2006) identified success factors for the integration of sustainability at early stages of design, the top three are: customised eco-design tools tailored for the company's needs, use of environmental checkpoints, reviews, milestones and roadmaps, good management commitment and support. The top three factors for the integration of sustainability at later stages are: environmental issues playing a role in all business activities, environmental design guidelines, rules and standards very specific to the company and inclusion of environmental issues in a company's technology strategy.

As a preliminary reflection of this last section, it can be said that there are two main constrains preventing designers to use eco-design tools, one is internal and the other external; the latter implies great complexity, it is about changing companies' culture regarding sustainability, improving communication and information exchange between different areas inside companies, behavioural change in consumers, market demand among others. The former is where this research project focuses, in pushing the boundaries of designers and explore potential new tool characteristics.

2.6. - ECO-DESIGN TOOLS

Contemporary culture says that tools by themselves are pointless; they achieve their purpose in the hands of the executor, and it is only his or her skills that will create the desired outcome. Nevertheless, when the purpose of the tool is to complement or even fill-in for the lack of those skills, tools become much more, they form part of, and enable the 'reflective conversation with the situation… and the situation talks back' (Schön 1983).

The purpose of this section is to briefly present other, more generic, characteristics of eco-design tools proposed by researchers, and present the results of an overall review of some of such tools available today.

In his PhD thesis Self (2011) identified five co-dependent relationships between tools and users: character and affordance of individual tools, designer's expertise, Influence of pragmatic requirements of design process, working culture, designer's idiosyncratic use of tools; all closely related to Stevenson (2013) findings.

Self (2011) also proposed what he called 'Universal Characteristics of Design Tools': mode of communication, level of ambiguity, transformational ability, level of detail, level of commitment.

Jones (2003), similarly proposed considerations for new eco-design tools, this time specifically for early stages of design:

- Their intent, complexity and instructions need to be carefully considered
- Take up is mainly determined by their ability to integrate into existing processes
- System-level idea generation or problem solving requires the drawing up of a system hierarchy
- Providing prompts or thematic information can be used to affect the outcomes from workshops

Wimmer and Züst (2001), created Ecodesign Pilot, which consists of an online analytic tool, working alongside of a series of principles in the form of a guideline. In their work, they clarify the need to detect the life cycle phase (raw materials, manufacture, distribution, use, end of life) where the highest impact (intensity) is occurring, in order to propose an appropriate structure of 'environmental management systems'. Nevertheless, they have found that a desirable macro-structure is difficult to achieve, due to the limited or some times non-existent relations among departments in companies (Wimmer and Züst 2001), which becomes a challenge for future eco-design tools.

The lack of demand in incorporating environmental or sustainable principles in product development, creates in turn no interest in eco-design tools, as found by Luttropp and Lagerstedt (2006). Also taking into account the dependency of decisions made in early stages of product design in relation to future environmental solutions' applicability and cost allocations, many designers see a contradiction between eco-design and economic growth.

In an interesting case study with Electrolux, Thompson and Sherwin (2001) found that 'corrective' eco-design usually leads to product improvement rather than product innovation. Finally, in a different case study Gertsakis (2001) identified the need to include other 'pivotal players' in general product development. These were senior executives, accountants, financial officers, suppliers, etc. In the exercise was expressed that 'someone needs to introduce social and ethical factors into mainstream business and the design process' (Gertsakis 2001).

In order to provide a compelling vision, the search for eco-design tools was extended beyond traditional scientific literature, and covered private initiatives of renowned companies, small and large companies offering specific analytic products, open platforms, books, internet sites, government initiatives among others. Because of the private or commercial nature of some of them, the researcher had limited information available, nevertheless where possible, images of screen shots are included, this is of high relevance because of the tools' characteristics for a possible applicability in early stages of design, where the amount of elements, the colours used, the complexity in the interface, different screens to visualise the information, etc. translate into an appropriate cognitive load for designers in a creative phase are key for their success, issues that will be further discussed at the end of this chapter and in chapter 4 (p.134).

In order to organise the findings the classification by Knight and Jenkins (2009), was used, where three categories were identified:

- Guidelines: 'providing broad support, with little detail, but applicable either across the whole product development process and lifecycle'.
- Checklists: 'providing in-depth, but narrow, application at selected stages of the product development process or lifecycle'.
- Analytical tools: 'providing detailed and/or systematic analysis at specific stages of either the product development process or lifecycle'.

Due to the computational nature of the tool developed in this research and that is detailed in chapter 4, the categories "guidelines" and "checklist", tools that are normally not interactive as defined in section 4.1 (p.135), will merge into one list, and its analysis will focus exclusively in the graphic solutions used, such as if uses colours to code information, if it tends to communicate with icons and figural representations or with text, if information is presented in only one page or multiple, etc.

GUIDELINES AND/OR CHECKLISTS

- Business-Ecodesign IDSA

  Created in 2000 it contains series of guidelines for eco-design and methods for calculating impact, all addressing business integration (IDSA 2000). It contains mostly text and tables with numeric information and no coded use of colour, which makes it slow to read and connect different points. It is presented in a PDF file with 8 pages.

Fig. 2.9 Business-Ecodesign IDSA

- COMPASS Design to Improve Life

  From the organisers of the INDEX Design Award (INDEX 2014), this 'compass' proposes four different steps: prepare; perceive; prototype and produce. Within each four guiding points, which must be dealt from three different perspectives: form; impact and context. This information is presented mainly through icons organised in a circle's quadrants, the icons appear all in black with no distinction between quadrants, which may create confusion; quadrants have a defined colour.

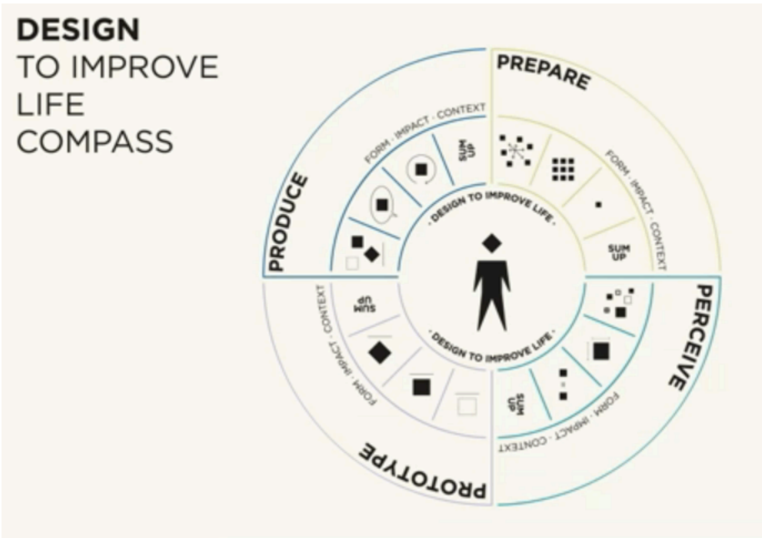


Fig. 2.10 COMPASS, Design to improve life

- Design 4 Sustainability

  Created by UNEP (1997) and TuDelft, consists of a series of guidelines and checklist. It is complemented with project examples. It consists mostly of text with some images of projects, no particular coded use of colour or icons representing concepts; it is accessible in a PDF file with 124 pages plus worksheets.

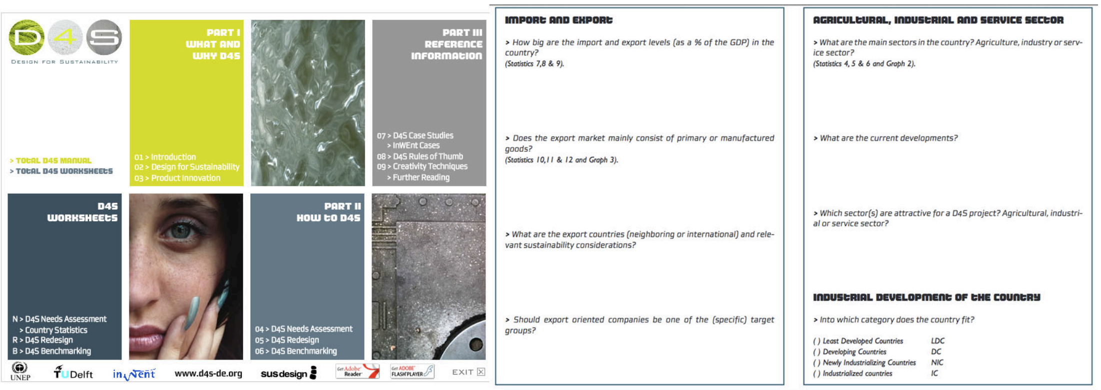


Fig. 2.11 Design 4 Sustainability guide

- Designers Accord Sustainability Tool Kit

  Webpage created in 2009 by a group of academics and professionals. They propose eight strategic questions and provide advice and guidance (Designers-Accord 2009). Entirely text based, very slow to read; information appears in different screens with simple but not friendly navigation.

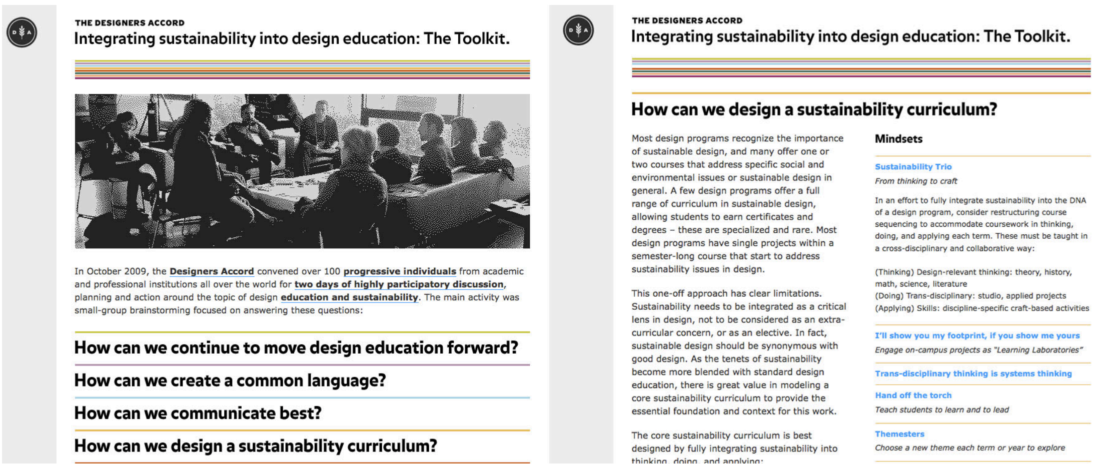


Fig. 2.12 Designers Accord Sustainability tool kit

- Eco-Design Directive for energy-related products

  Promoted as a framework for guiding manufacturers of energy-consumer products to reduce the energy usage, plus other environmental impacts throughout the entire life cycle (ECEEE 2009). Online-based, consist of a main graphic defining the five directive steps which links to subsequent pages with more specific information and some text documents for download. Entirely text-based, the sections are colour coded, navigation in several pages which makes it slow and slightly confusing.

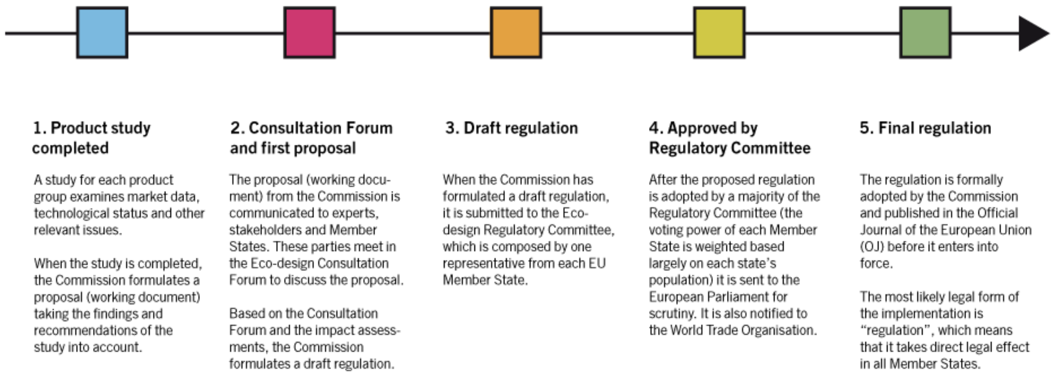


Fig. 2.13 Eco-Design Directive ECEEE

- Lunar Designers Field Guide to Sustainability

  Created by the Californian design consultancy Lunar (2014), it is similar to INDEX's compass, it covers four main aspects: What is trying to be accomplished? How is it brought to life? How is it used? Where does it end up? Presented in a circle's quadrants and colour coded. Each of these contains specific guiding points that are represented with an icon all of them in colour blue. Nevertheless, it is mostly text-based. It is accessible in a PDF with 6 pages.

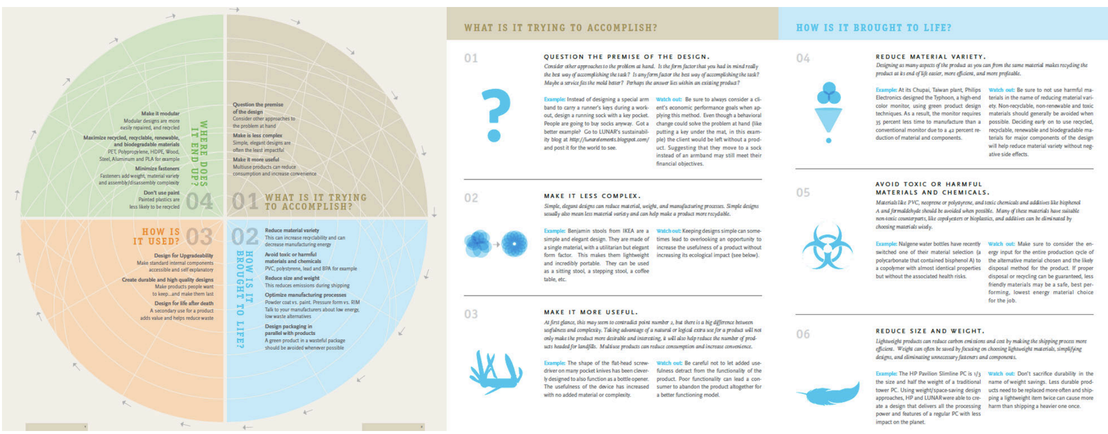


Fig. 2.14 Lunar's Designers Field Guide to Sustainability

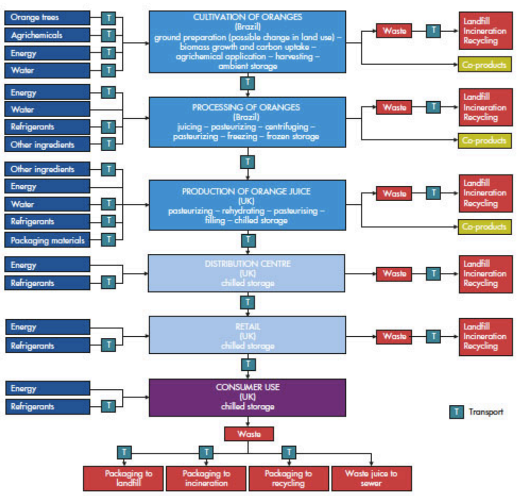
- Okala Eco-design Strategy Wheel

  Following the life cycle of a product, it proposes 8 steps with a particular focus: Innovation, Materials impact, Manufacturing innovation, Distribution impacts, Behaviour and use impacts, Systems longevity, Transitional systems and End of life (White, St. Pierre et al. 2014). Each is colour coded and contains specific guiding points; interestingly they highlight the interconnectivity between them, it is presented in a PDF file with 61 pages, and the file is "navigable" through a series of links between pages showing this interconnectivity. It is mostly text-based with images as examples.

Fig. 2.15 Okala Strategic wheel

- PAS 2050

  Created by BSI (2015) as a response to the requirement for a method to measure greenhouse gases emission along the entre life cycle of products and services, which were simpler than LCA and directed for SMEs. It is accessible as a PDF file with 74 pages, mostly text with some graphics, tables and images, many of them with large amounts of information.



	Quantity	Unit	Transport distance (for input or waste)	Transport mode and type	Data source
Input					
Oranges	5,000	kg	100 km	Articulated HGV >33 t	Published/reviewed LCA, assumed transport
Water	100	litres	–	–	Published/reviewed LCA
Refrigerants	0.05	kg	100 km	Articulated HGV >33 t	Published/reviewed LCA, assumed transport
Cleaning detergent	10	kg	100 km	Articulated HGV >33 t	Published/reviewed LCA
Energy					
Natural gas	30	kWh	–	–	Published/reviewed LCA
Grid electricity	65	kWh	–	–	Published/reviewed LCA
Product outputs					
Orange concentrate	1,000	kg	–	–	Published/reviewed LCA
Orange pulp	400	kg	–	–	Published/reviewed LCA
Orange peel oil	125	kg	–	–	Published/reviewed LCA
Waste					
Damaged oranges	100	kg	10 km	Rigid HGV >7.5–17 t	Published/reviewed LCA, assumed transport
Pith/peel/pips	150	kg	50 km	Rigid HGV >7.5–17 t	Published/reviewed LCA, assumed transport
Waste water	3,325	litres	–	–	Published/reviewed LCA
Cleaning detergent to waste water	10	litres	–	–	Published/reviewed LCA
Refrigerant emissions	0.05	kg	–	–	Published/reviewed LCA

Fig. 2.16 PAS 2050

- Sustainia

  This webpage created by Sustainia (2011), a think tank and consultancy headquartered in Copenhagen, collects annually the best 100 sustainability projects and solutions, to collectively represent a guide for better practice. It also organises an award in annual basis. Good balance of text and the use of graphics and images, which makes it easy to navigate and interesting at first sight.

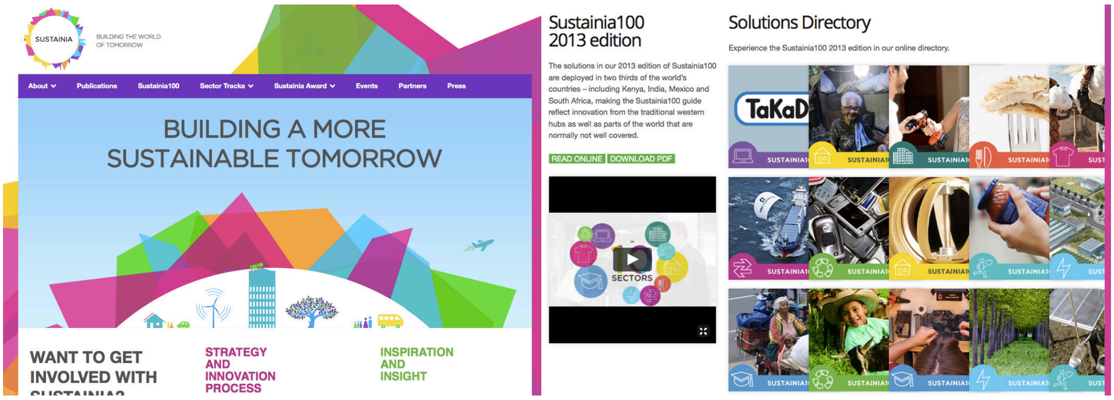


Fig. 2.17 Sustainia screen shot

- Eco-Cost TuDelft

  Created at the Technological University Delft by Dr. J. Vogtländer (2011), this is a ‘measure to express the amount of environmental burden of a product on the basis of prevention of that burden’. It represents the cost that should be incurred in reducing the environmental impact and materials depletion within the carrying capacity level of our planet.

  First, this tool provides the concept of a value ratio of a product in relation to the cost to prevent its adverse impact. This is done by providing a very large data spread sheets, which are downloadable with the calculated eco-cost of more than 6,500 products and services. Secondly, this tool also provides a simple guide for performing a ‘fast track’ LCA, also in a spreadsheet. Very large amount of information is found in text and numerical values, which is very difficult and slow to read (TU-Delft 2015).

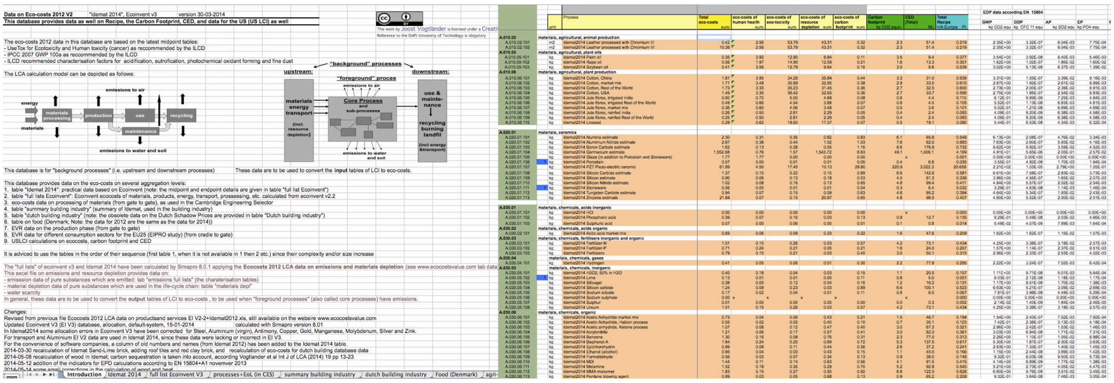


Fig. 2.18 Eco-Cost screen shots

- Information / Inspiration

  Webpage created by Dr. Vicky Lofthouse (2005), addresses the need of information and inspiration for designers wanting to do sustainable design. It contains case studies for inspiration, with relevant information ranging from where to start, tools, guidelines for each life cycles step and legislations. The structure of the website is easily navigable through an always visible menu on the left side of the screen. The website provides mostly text-based information with images as examples.

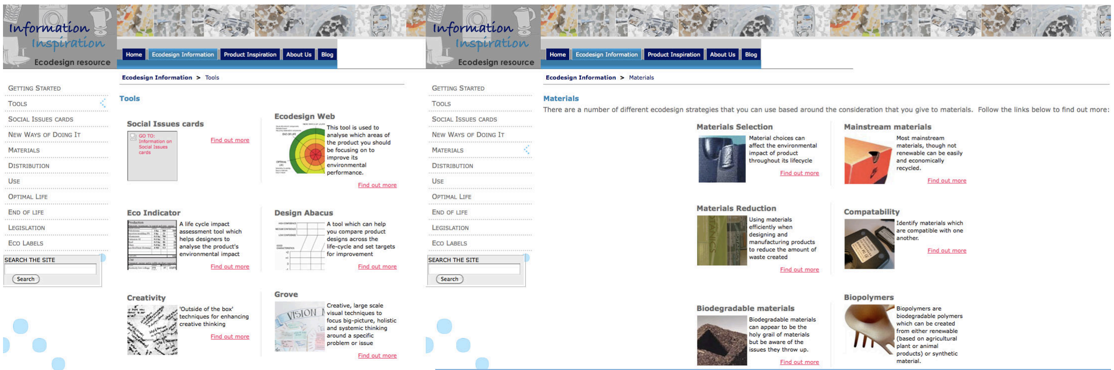


Fig. 2.19 Information / Inspiration screen shots

- Design Play Cards

  Created by Eco-innovators (2013) in Australia, this is a set of cards with three themes; design problems, design inspiration, and design strategies. Free to download are available for the users to print. It is includes basic instructions on how to use the cards when tackling a design problem. Each of the three themes are colour coded, the cards are heavily written in order to explain the point, but every card also contains a small graphic to represent the written statements.

Fig. 2.20 Design Play Cards

The previous guidelines and checklist provide a few simple clues on what characteristics are more appropriate for the working culture of designers at early stages of their design process. For example: avoid providing information in multiple pages or screens, as well as large amount of text; coding information through colours and/or icons helps relate information in the different steps of the life cycle; visually identify the sequence of the life cycle steps; use different complexity levels of information, this is simpler and more visual initially, and in case of need or interest provide access to more detailed information where text and numbers are expected; provide guidance through the entire process in order to understand what is next and what the options are; avoid as much as possible complex mathematical calculations; provide aid to identify the challenges and give the correspondent strategies to solve it.

ANALYTICAL TOOLS

- SimaPro

  Full Life Cycle Assessment software by Dutch company Pré (2014) using European Ecoinvent database. The software is based on the four sections of an LCA, it does not have a clear indication or visualisation of the life cycle or the connections between its steps until input of data is finished. The entire interface is written with tree lists that are displayed in a second window with more specific obtainable on selected variables. Further information is displayed through pop up windows, all in great amounts and highly technical terminology, figure 2.21.

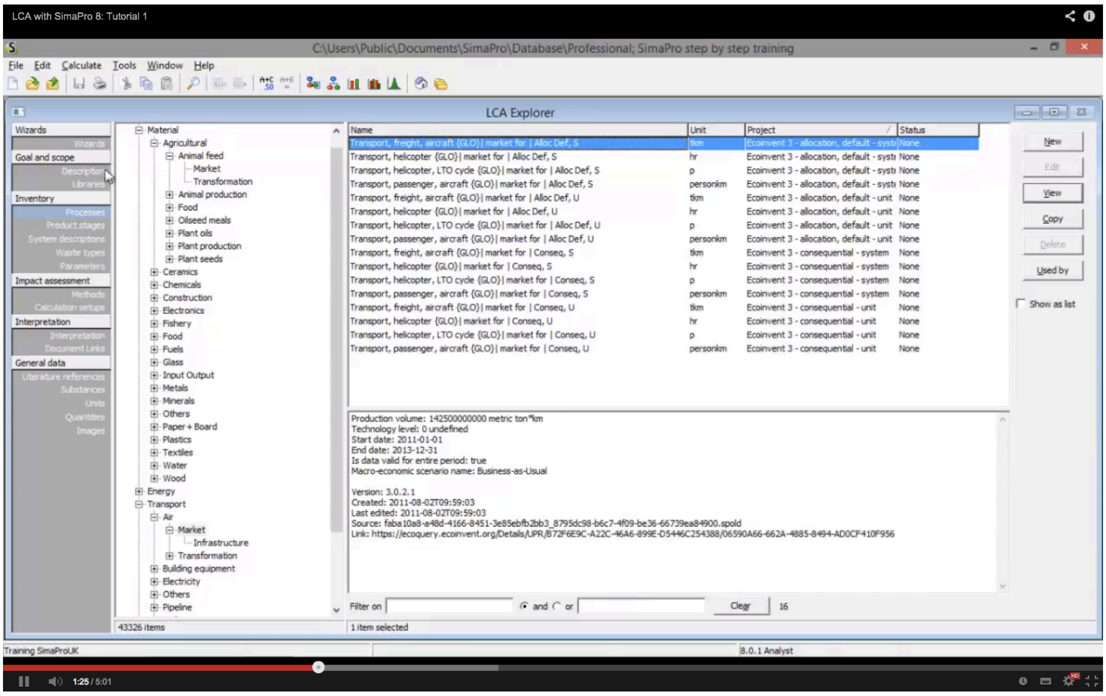


Fig. 2.21 SimaPro main interface, by Pré

Results are displayed in form of pie charts and bars as well as numeric data in excel-type charts, all in additional windows. The cycle can be visualised in a sankey diagram, figure 2.22. Navigation is complex and there are great amounts of text that makes it slow to learn and use.

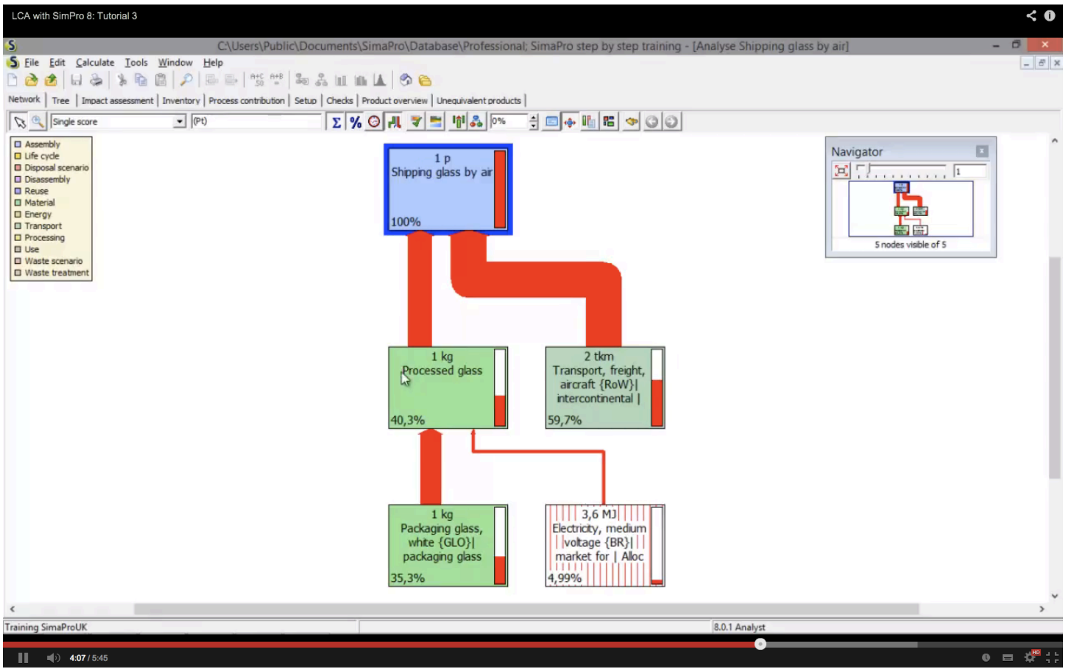


Fig. 3.22 SimaPro process flow screen, by Pré

- Umberto

  Full Life Cycle Assessment software by the German company IFU (2014). They provide four different versions: ‘LCA’, ‘CO2’, ‘Efficiency’ and ‘Universal’, all using European Ecoinvent database. The software starts with a main central space where the different processes of the life cycle are drawn and specified, all variables are accessible in smaller left side windows, figure 2.23.

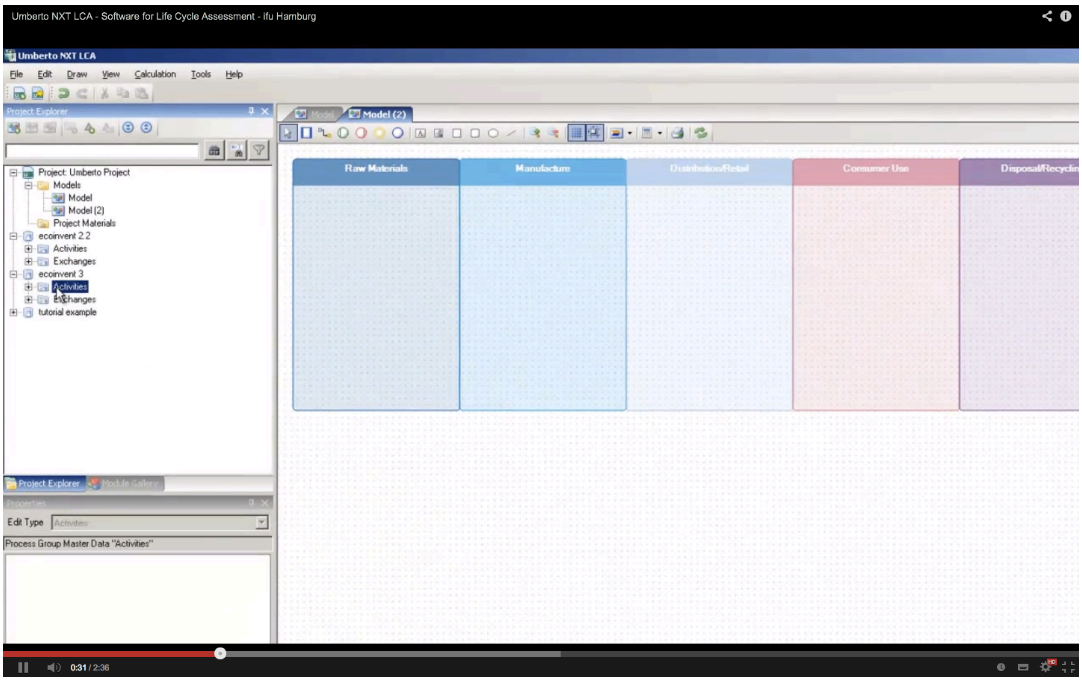


Fig. 2.23 Umberto main working space, by IFU

Later these processes are connected creating the cycle that is presented in linear form, even if recycling is specified. The software identifies the life cycle steps and colours the background distinguishing each one of them, figure 2.24. Some of these processes are pre-specified by the software and cannot be modified. All creation and editing elements are always visible. Results are presented in very simple graphics that are difficult to understand. All information is highly detailed with very technical terminologies.

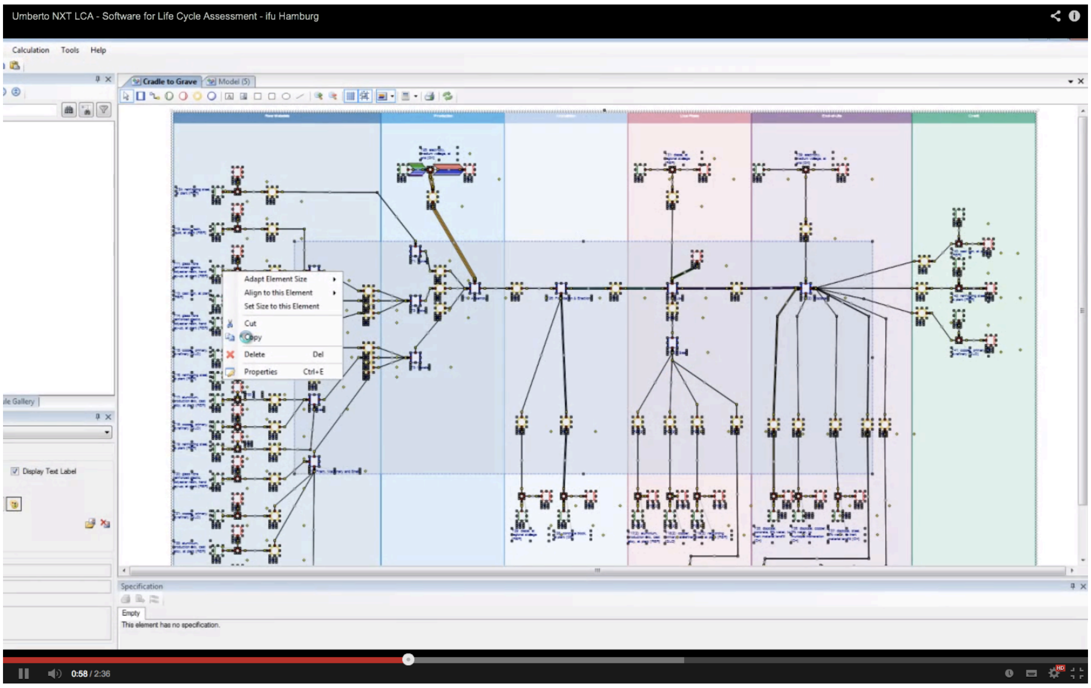


Fig. 2.24 Umberto all process linked, by IFU

- GaBi

  Full Life Cycle Assessment software by the German company PE International (2014). They provide four versions: 'envision' (for early stages of design), 'server', 'DFX' and 'Education'. Similarly to Umberto the processes are first created and then linked. One important difference between the two is that GaBi uses a great number of different windows for the working space and the variables to be input, but Umberto does not. All information is in written format with numerous fields and highly technical terminology, and no graphics, figure 2.25.

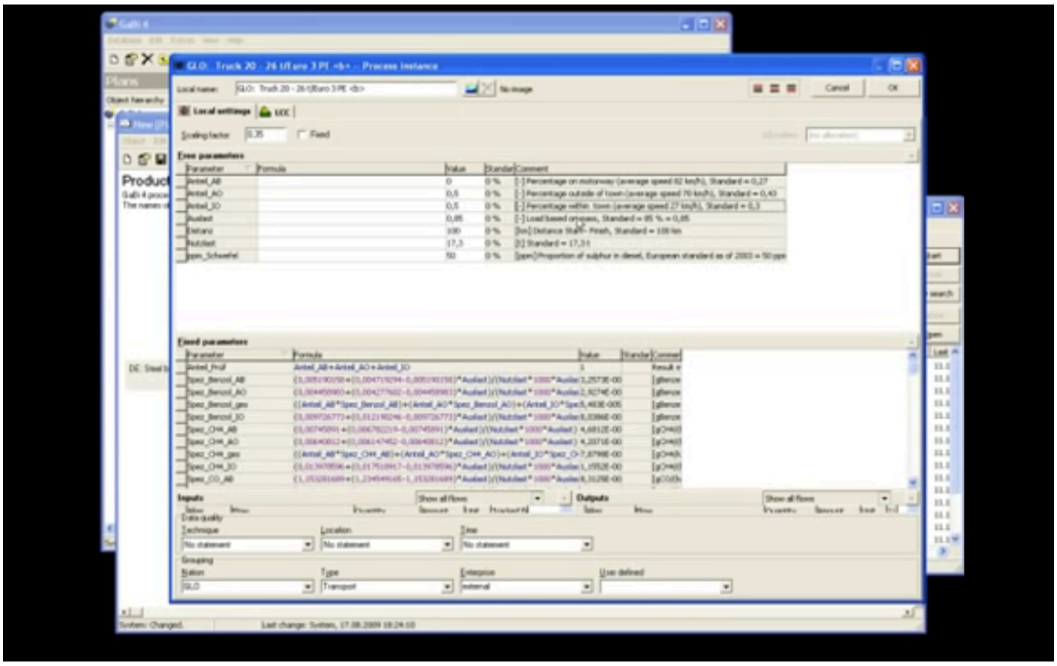


Fig. 2.25 GaBi screen shots, by PE International

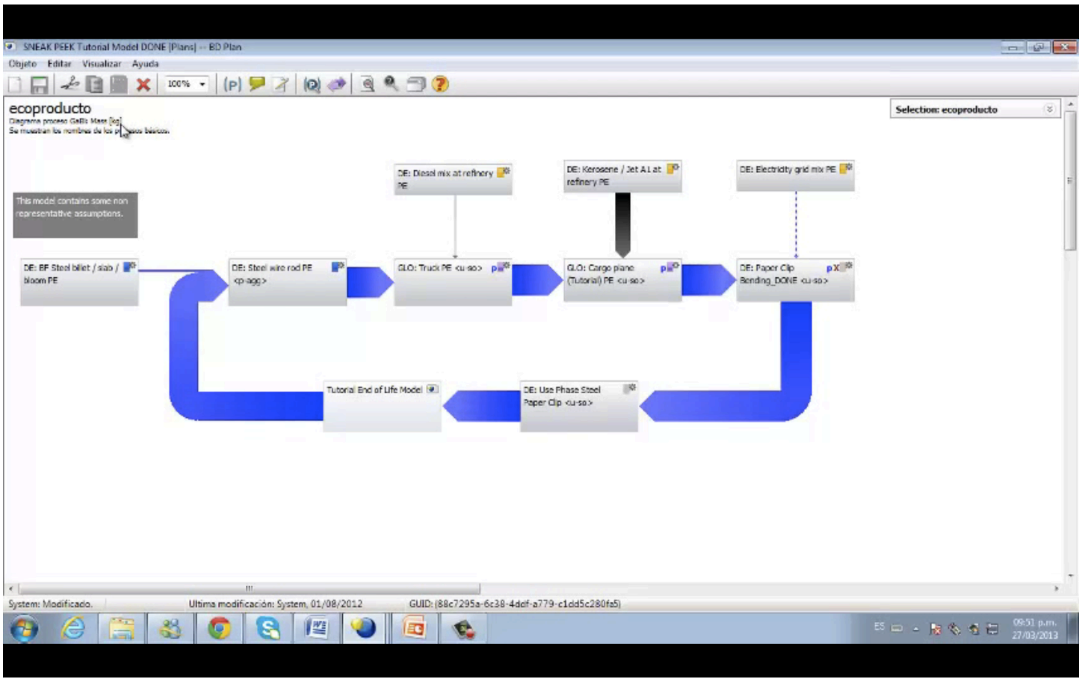


Fig. 2.26 GaBi - Visual representation of the cycle can be cycled back to the origin, therefore closing the cycle, by PE International

Results are displayed in high detail with numerous colour coded bar charts, depending on the type of impact and origin in the life cycle, figure 3.27.

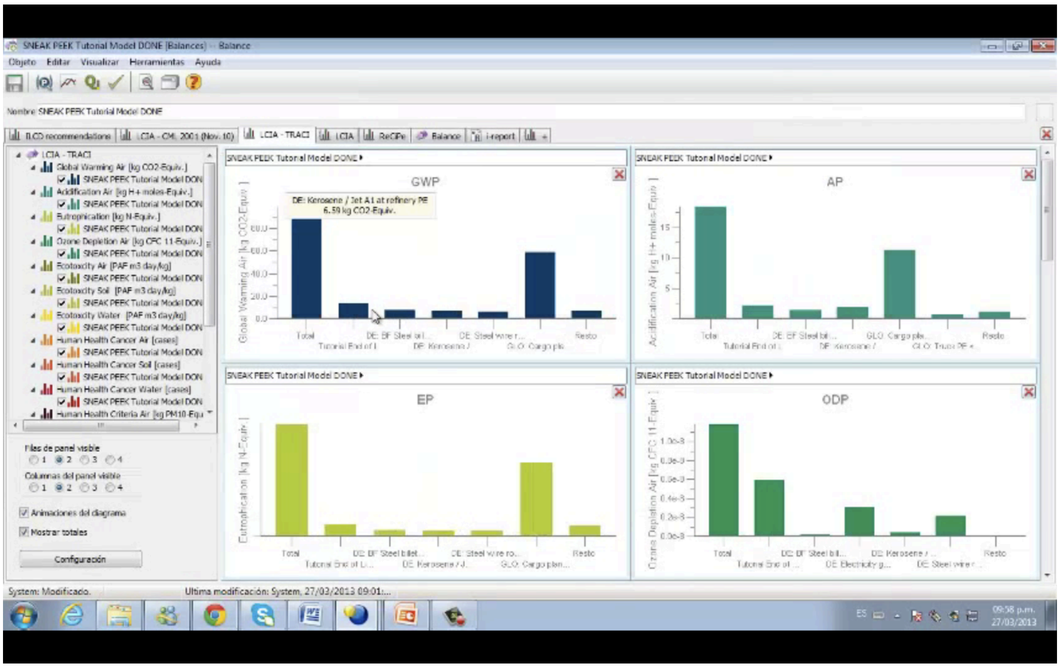


Fig. 2.27 GaBi results screen, by PE International

- LCA Calculator

Full Life Cycle Assessment software by the British company IDC (2014). Meant to "aid in the sustainable design of new products by comparing concepts with real products and competitors". It displays the life cycle steps in the form of tabs on top of the screen. Basic components are displayed and selected through drop down menus with each tab. The total number of available materials and manufacturing processes has been reduced in comparison to the previous described three tools (Simapro, Umberto, GaBi), but still this tool is quite long and contains technical terminology, figure 2.28.

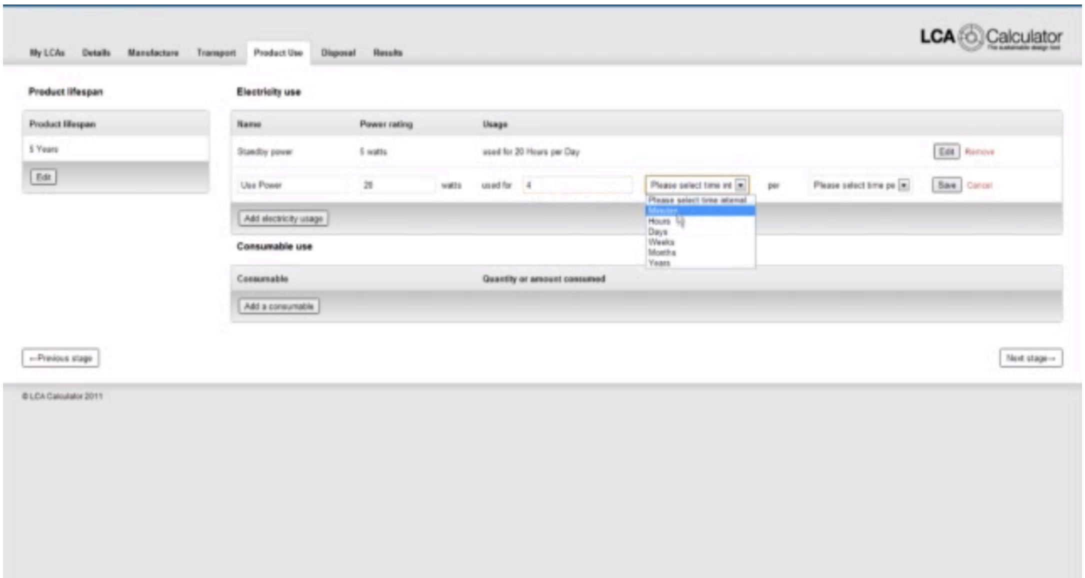


Fig. 2.28 LCA calculator main working screen, by IDC

It does not provide a clear visualisation of the life cycle and its connections. One interesting characteristic this tool holds is the possibility of specifying how much of certain material will be recycled through sliders that create an interactive experience. Results are displayed with two large icons representing, for example the total CO2 emissions of the product and a correspondence in kilometres that a small family car will drive producing the same amount of CO2. All the other results are displayed in colour coded pie charts and bars in relation to the life cycle steps. Nevertheless, this colour coding is not present in the tabs or any of the windows where the variables of each step are introduced, figure 2.29.

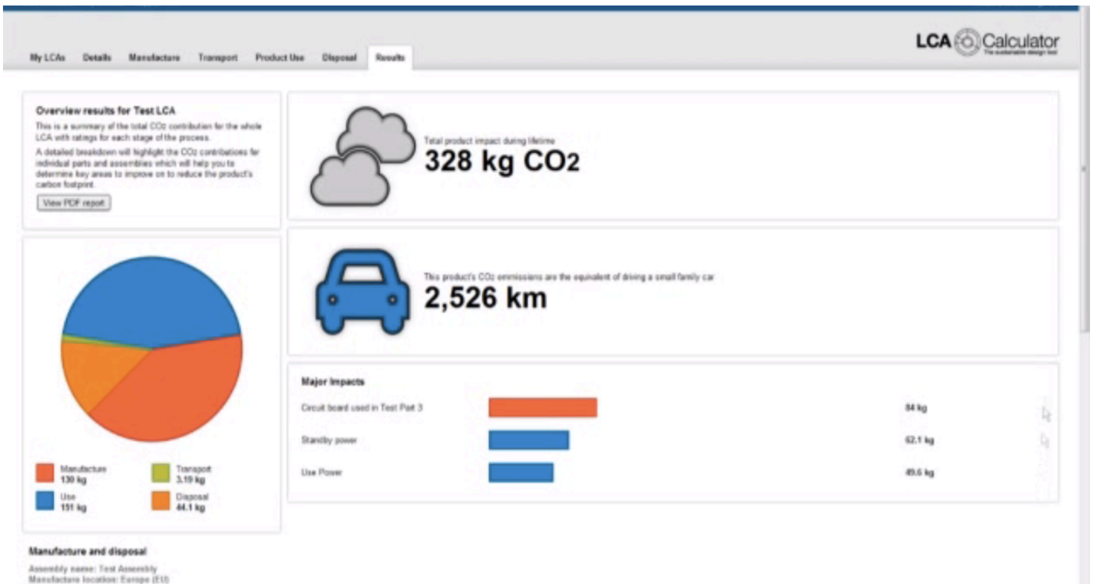


Fig. 2.29 LCA calculator screen shots, by IDC

- Open LCA
  Free and open source full Life Cycle Assessment software by the German company Green Delta (2014). This tool does not include any databases, but is compatible with several independent databases. The main interface guides the user into the inputs and outputs of the life cycle. All variables of the life cycle steps are introduced through popup windows, and must be written in excel chart-type fields, figure 2.30. Later the processes are linked into a “system”.

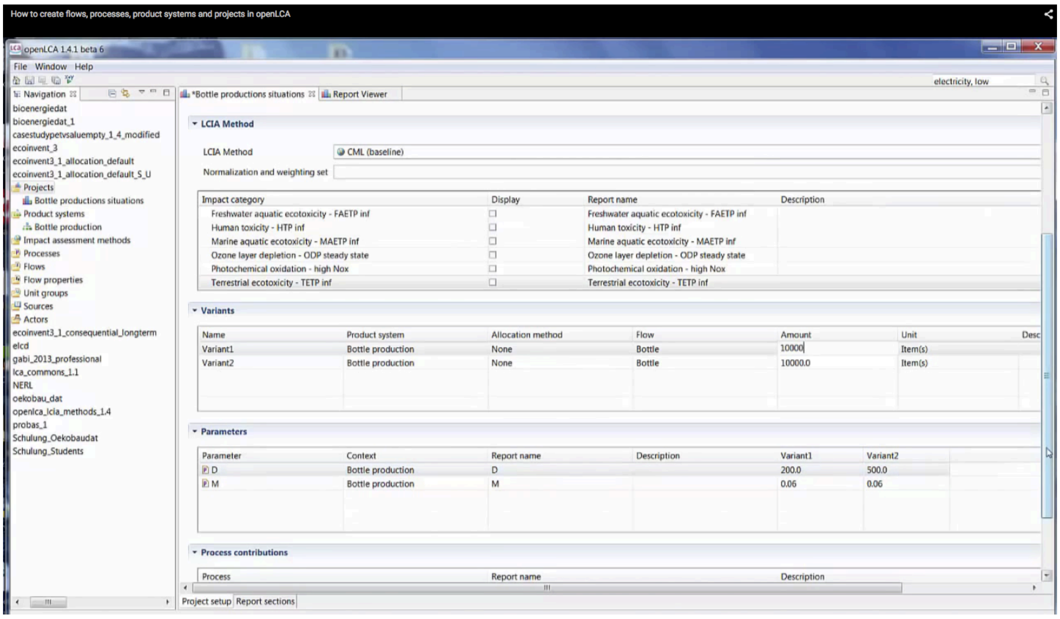


Fig. 2.30 Open LCA main working screen, by Green Delta

There is no clear understanding and visualisation of the life cycle until finalised and requested. Results can be displayed in multiple ways, figure 2.31. All navigation is made through tabs on top of the screen.

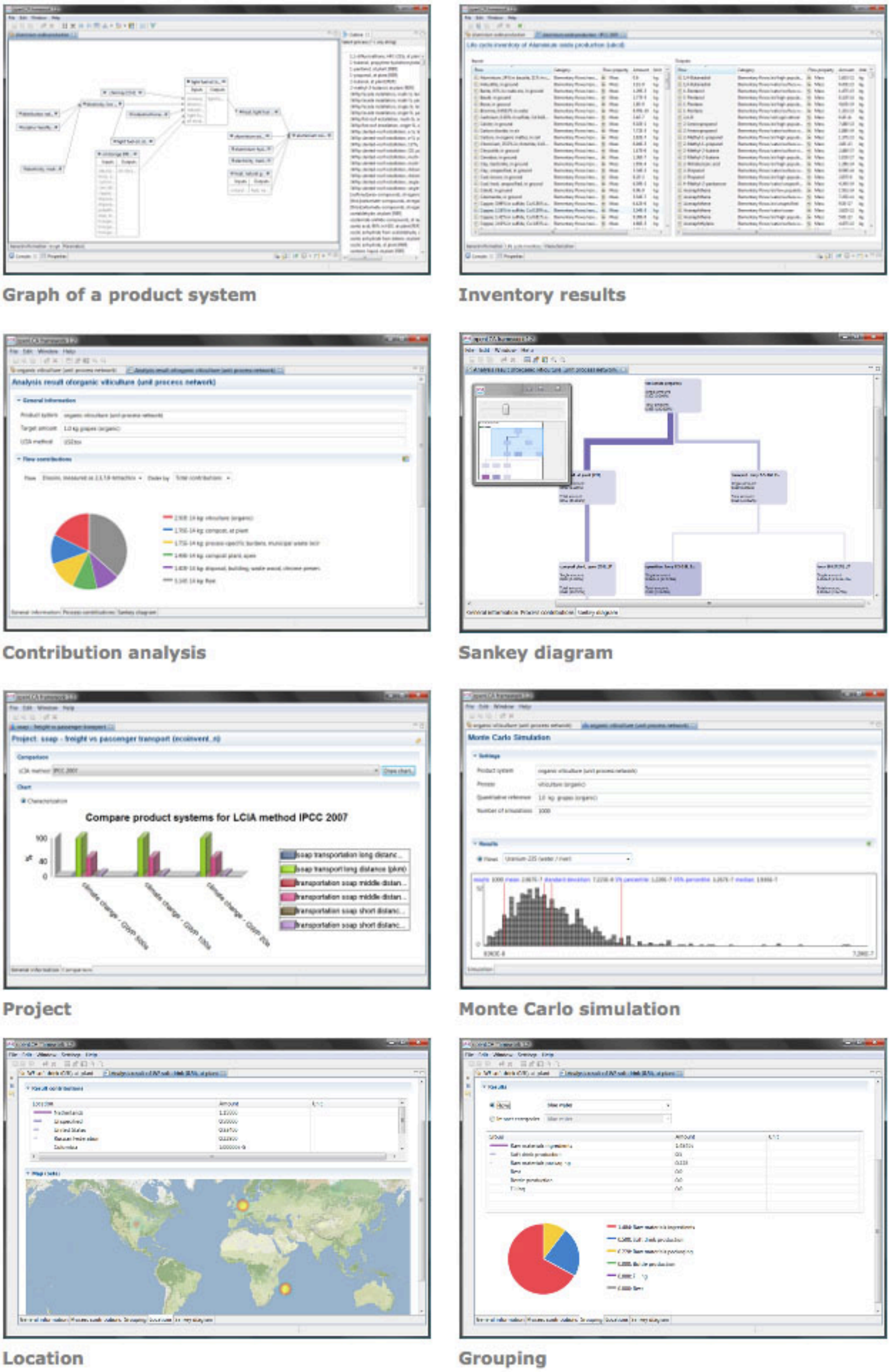


Fig. 2.31 Open LCA Multiple result displays, by Green Delta

- Granta Eco-Audit and Granta MI

  Material information management software by the British company Granta (2014). It provides two software: ‘Granta MI’ (Material Information), and ‘CES Selector’ that specialises in materials and its characteristics, it has a module named ‘Eco-Audit’ (publicised for early stages of design). Eco-Audit considers environmental impacts of “what if” scenarios. It is not focused in the life cycle; it highlights alternatives of material performance and the cost options, figure 2.32.

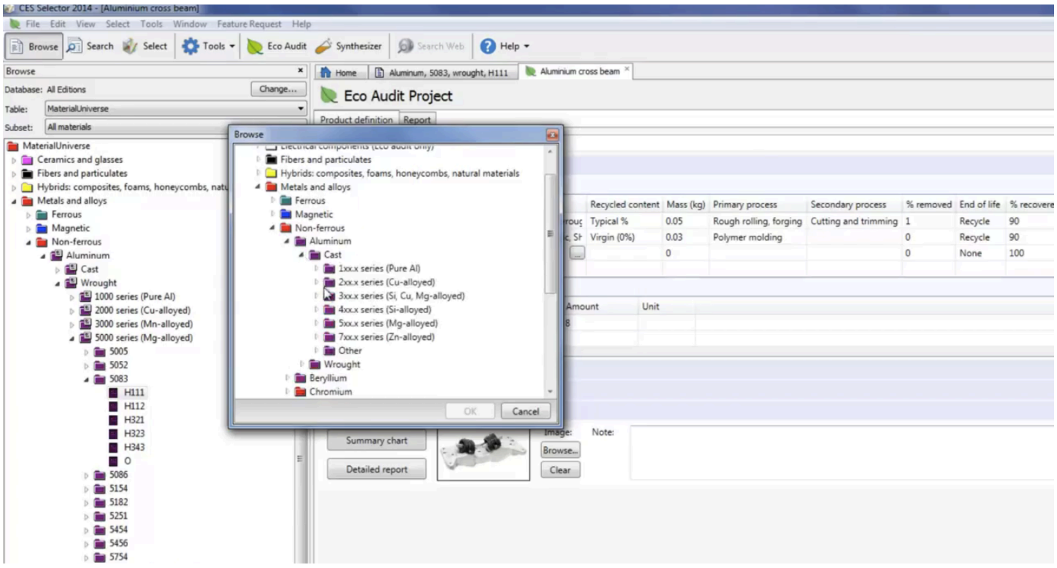


Fig. 2.32 Granta Eco audit main working screen, by Granta

The life cycle is presented in a linear fashion even when ‘recycled’ is specified for the process. Results are displayed in charts with ‘bubbles’ and in graphics with bars, figure 2.33.

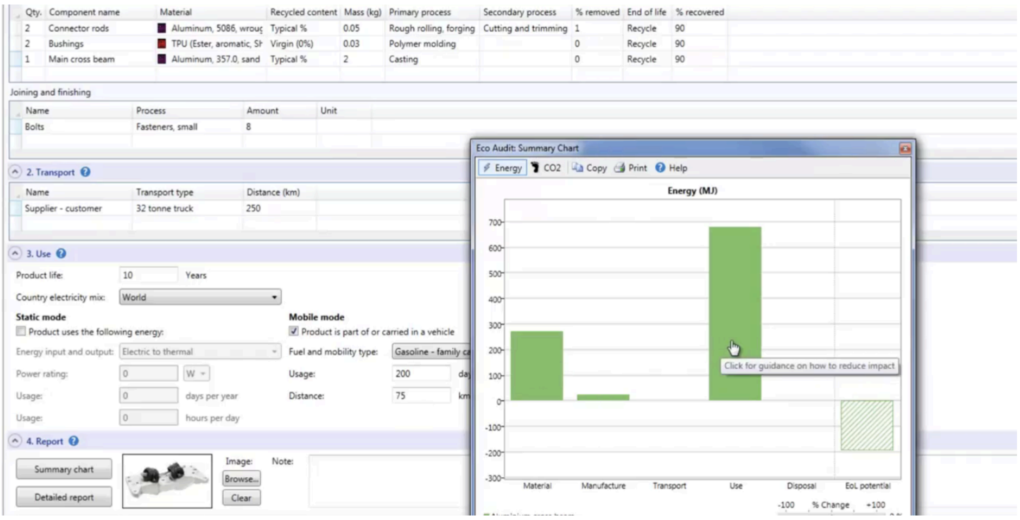


Fig. 2.33 Granta Eco audit results pop up window, by Granta

- Sustainable Minds

  Online LCA software, company based in Cambridge, MA (Sustainable-Minds 2014). (Stated purpose of estimate, evaluate, compare and track – while designing). It has three steps: first is definition, where the user inputs in written format the scope and goals; second is create where the user references products and new product concepts; lastly compare and interpret, where users state the results, figure 2.34.

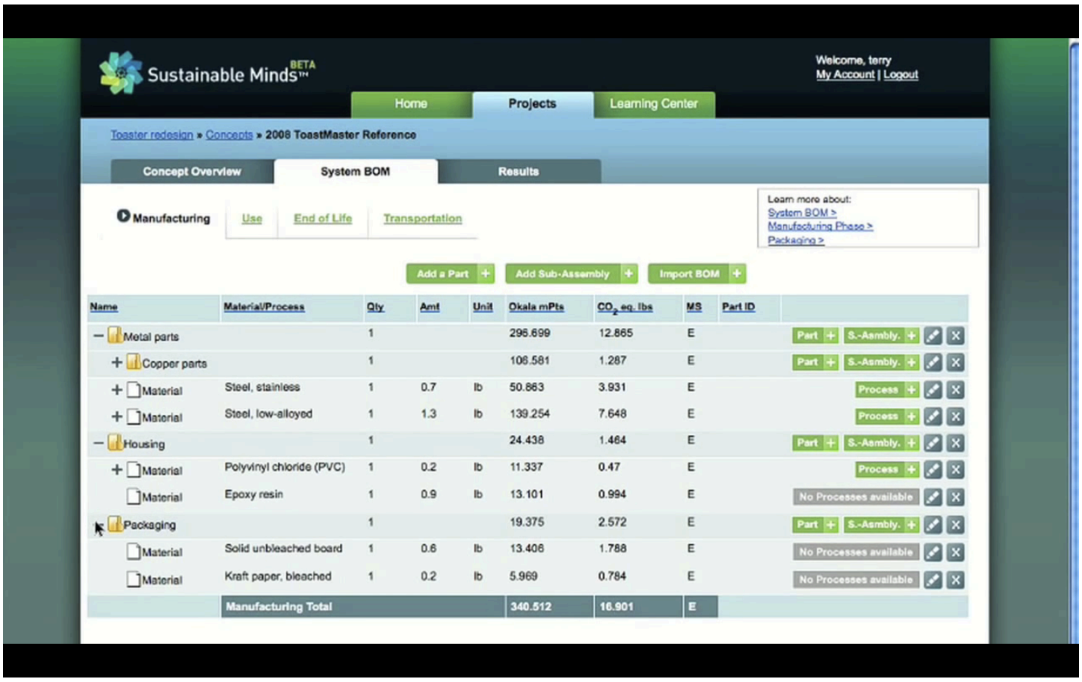


Fig. 2.34 Sustainable Minds main working screen

It includes eco-design strategies in a separate window. In general it provides less information than the tools presented first, but it has long lists of variables with subcategories in a “tree” format where sometime scrolling down is necessary. It highlights stronger impacts and the life cycle phase, which is displayed in bar graphics. There is no visual relation to the life cycle and if it’s closed.

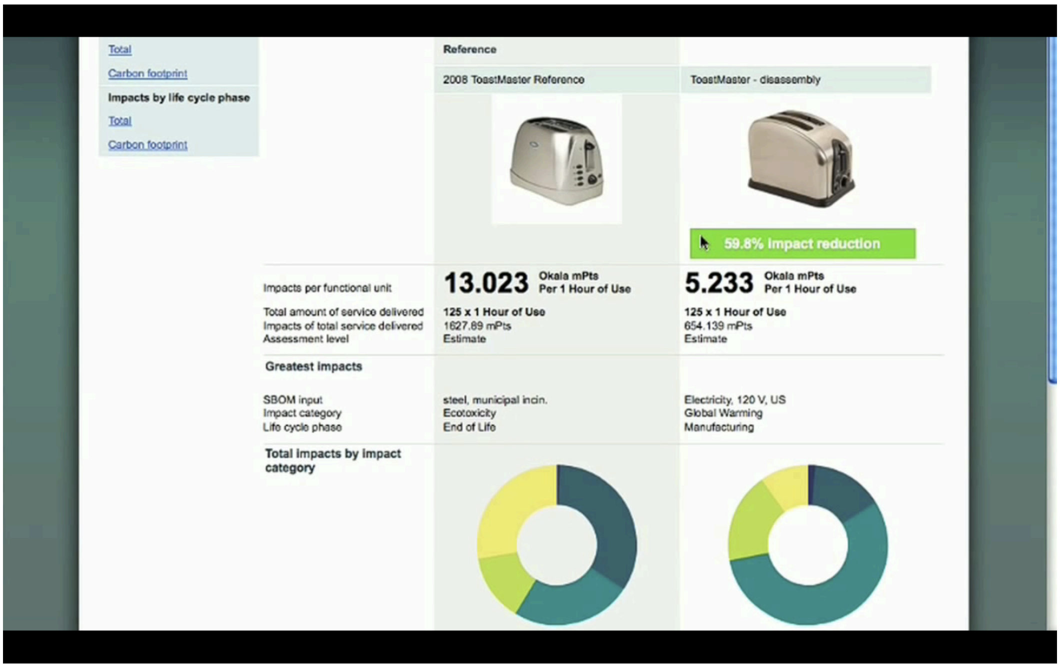


Fig. 2.35 Sustainable Minds compare concepts screen

- LCA to go

  European project involving eight countries (LCA-to-go 2014), the goal is to produce eco-design tools for the bio-based plastics, industrial machines, electronics, renewable energy, sensors and smart textiles sectors. The first tool was released in December 2013. It has two sections, “rough assessment” and “detailed assessment”. The former follows the life cycle step with tabs on top of the screen, each displaying the fields to input data, all in written format.

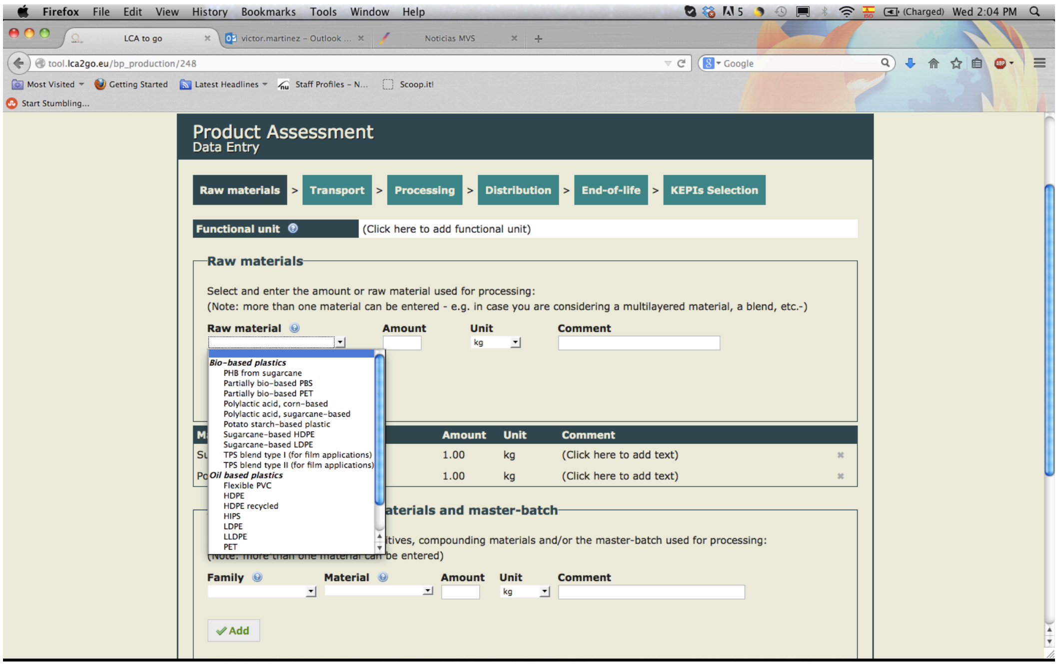


Fig. 2.36 LCA to go main working screen

Results can be processed in three “data qualities” robust, indicative or illustrative, and they are all displayed as percentages or detail figures according to the life cycle step with a representation in pie charts and bar graphics. This first section helps to quickly identify the “hot spot”. The second section of “detail assessment” more data with higher accuracy can be input. Some of these fields are highly technical and the level of technical terminology clearly increases. At the end a list of potential improvements is provided.

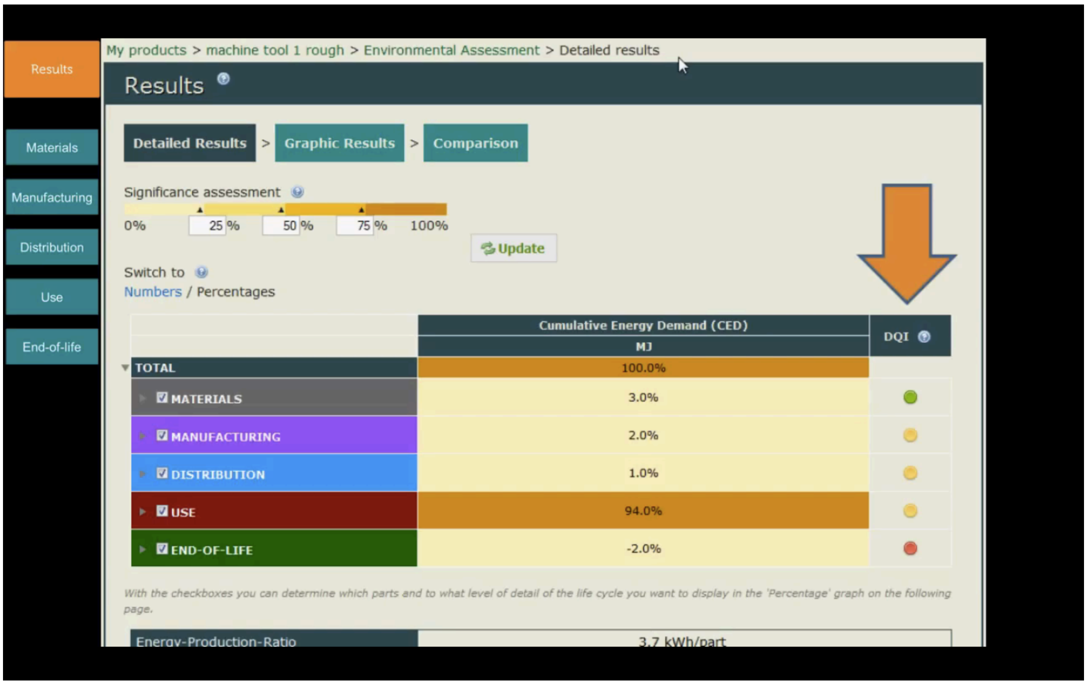


Fig. 2.37 LCA to go Life Cycle 'hot spot'

- EIO-LCA

  Free and online Economic Input-Output Life Cycle Assessment tool by Carnegie Mellon University (2014). Based in the work of Nobel Laurate Wassily Leontief it estimates the material and energy resources environmental emissions. This tool request only five steps to complete: first is the selection of the type of database to be used. Most of them are economic databases largely from the US. The second step is selecting the industry sector with a subsector or product. Defining the amount of economic value for any given product or production is the third step, figure 2.38.

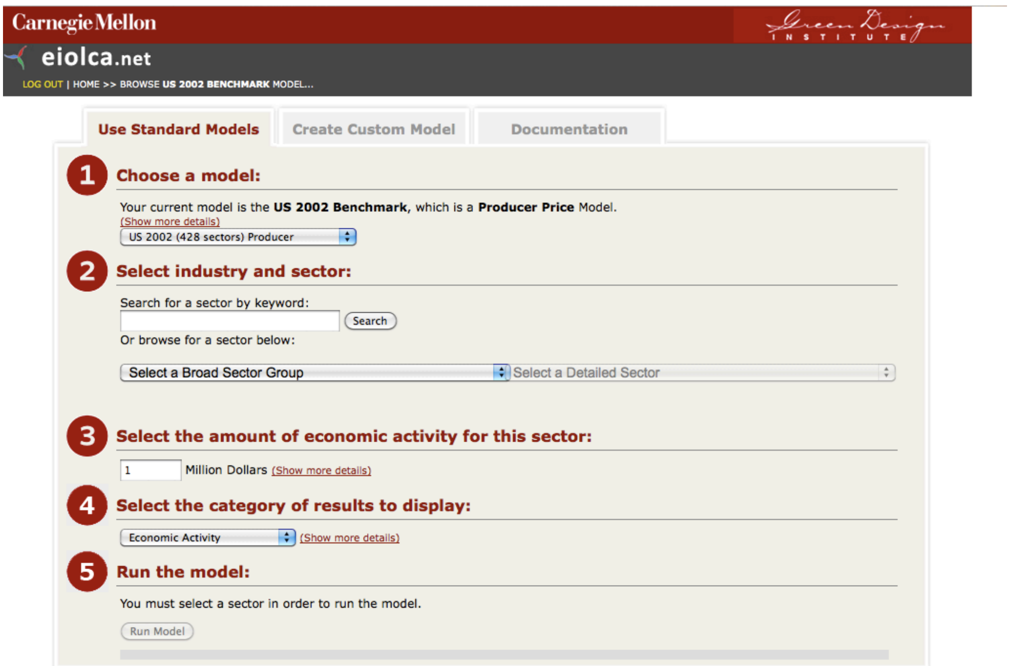
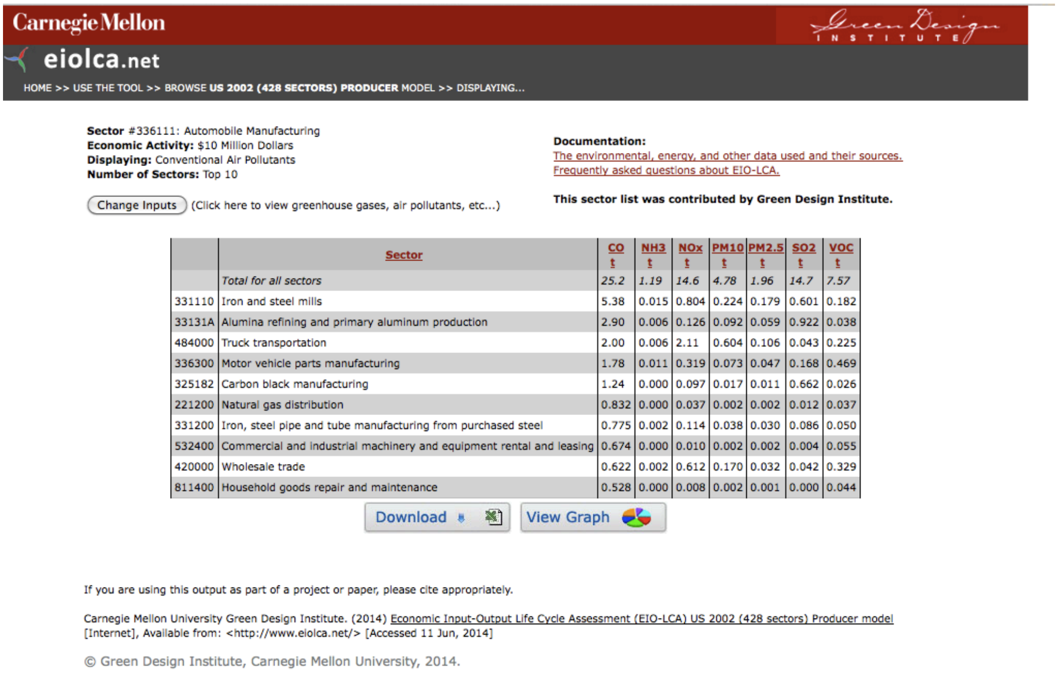


Fig. 2.38 EIO-LCA main working screen, by Carnegie Mellon University

The fourth step is selecting what type of results will be displayed: economic activity, greenhouse gases, energy, toxic releases or water used, figure 2.39. The fifth step is to run the model in order to obtain the results, which are displayed in numeric excel-type charts. If requested there is an option to visualise these results in pie charts. There is no reference to the life cycle of the product.


Carnegie Mellon
Green Design Institute
eiolca.net
HOME >> USE THE TOOL >> BROWSE US 2002 (428 SECTORS) PRODUCER MODEL >> DISPLAYING...

Sector #336111: Automobile Manufacturing
Economic Activity: $10 Million Dollars
Displaying: Conventional Air Pollutants
Number of Sectors: Top 10

Change Inputs (Click here to view greenhouse gases, air pollutants, etc...)

Documentation:
The environmental, energy, and other data used and their sources.
Frequently asked questions about EIO-LCA.

This sector list was contributed by Green Design Institute.

	Sector	CO t	NH3 t	NOx t	PM10 t	PM2.5 t	SO2 t	VOC t
	Total for all sectors	*25.2*	*1.19*	*14.6*	*4.78*	*1.96*	*14.7*	*7.57*
331110	Iron and steel mills	5.38	0.015	0.804	0.224	0.179	0.601	0.182
33131A	Alumina refining and primary aluminum production	2.90	0.006	0.126	0.092	0.059	0.922	0.038
484000	Truck transportation	2.00	0.006	2.11	0.604	0.106	0.043	0.225
336300	Motor vehicle parts manufacturing	1.78	0.011	0.319	0.073	0.047	0.168	0.469
325182	Carbon black manufacturing	1.24	0.000	0.097	0.017	0.011	0.662	0.026
221200	Natural gas distribution	0.832	0.000	0.037	0.002	0.002	0.012	0.037
331200	Iron, steel pipe and tube manufacturing from purchased steel	0.775	0.002	0.114	0.038	0.030	0.086	0.050
532400	Commercial and industrial machinery and equipment rental and leasing	0.674	0.000	0.010	0.002	0.002	0.004	0.055
420000	Wholesale trade	0.622	0.002	0.612	0.170	0.032	0.042	0.329
811400	Household goods repair and maintenance	0.528	0.000	0.008	0.002	0.001	0.000	0.044

Download View Graph

If you are using this output as part of a project or paper, please cite appropriately.

Carnegie Mellon University Green Design Institute. (2014) Economic Input-Output Life Cycle Assessment (EIO-LCA) US 2002 (428 sectors) Producer model [Internet], Available from: <http://www.eiolca.net/> [Accessed 11 Jun, 2014]

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Fig. 2.39 EIO-LCA results screen, by Carnegie Mellon University

- SDO-LENS Poli-Milano

  Sustainable Design Orienting (SDO) is a free, online tool kit, created by researchers at the Polytechnic of Milan (2014). It contains a series of checklists and guidance on eco-design principles. It first sets the priorities and goals of the project, then focuses on the concept, and finally orients the user through a higher detail checklist. The tool provides guidance with eco-design strategies, and has a particular direction towards systems and service design, figure 2.40.

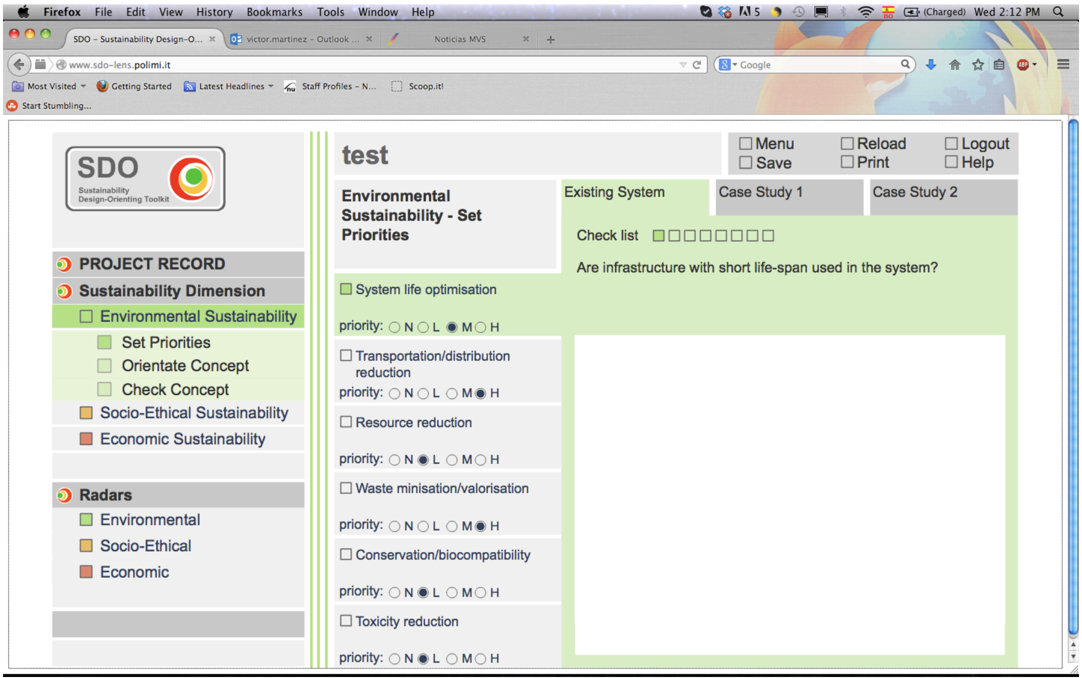

Fig. 2.40 SDO-LENS main working screen, by Poli-Milano

Lastly, the tool reviews the concept where the inputted information can be visualised in “radars” also called spider web diagrams, figure 2.41. The first set of checklists are answered by a pre set options accompanied with fields where specific information about the project con be written. The tool stresses out the importance of sustainability for the environment, the socio-ethic and the economic aspects. Navigation is clear but requires more guidance on what the user is supposed to do.

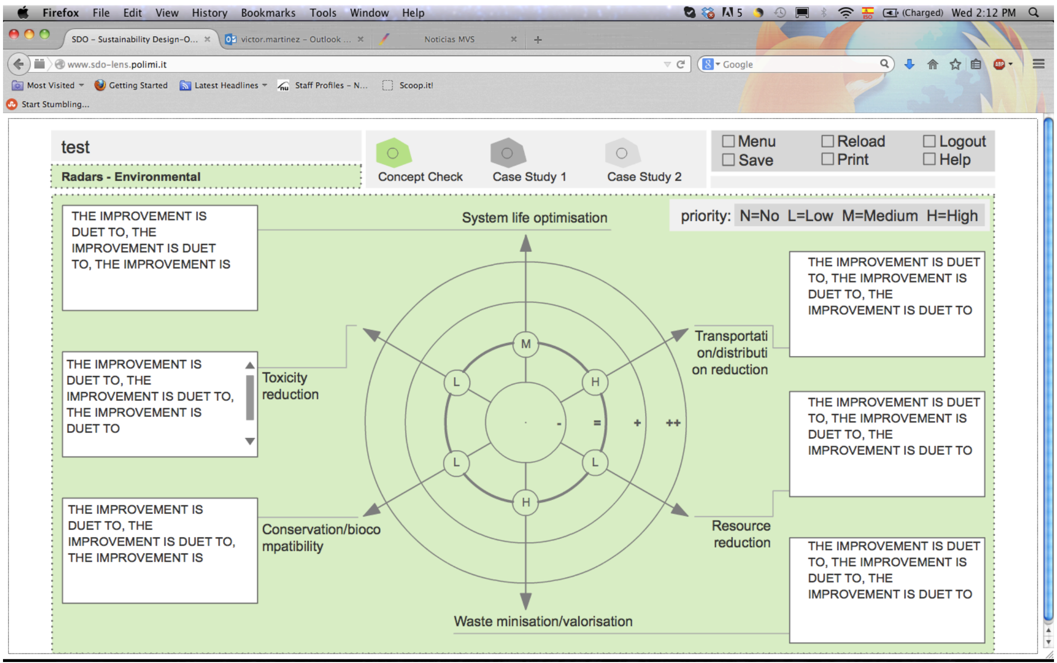

Fig. 2.41 SDO-LENS results screen, by Poli-Milano

- PILOT Ecodesign Toolbox

  Online, free checklist and guidelines for product development strategies, created by researchers at the Institute for Engineering Design of TU Vienna (2014). Their website states that the toolbox is meant to "improve existing products". It is life cycle based, and focuses on identifying the intensities of each step of the life cycle. According to the website the PILOT provides a list of eco-design strategies. Each Life Cycle step is analysed through a series of questions and fields to specify goals and actions, the user must write all of them, figure 2.42.

Fig. 2.42 PILOT initial screen with life cycle steps, by TU Vienna

It involves answering numerous steps and questions, making it very long and tedious. The website has a complex structure with many independent windows in levels and sublevels, and there is no clear visualisation of the Life Cycle or the connections between steps, figure 2.43. There is a complementary section called "assistant" where the Life Cycle is analysed in a simplified form by concentrating in main categories and reducing the number of variables to input, nevertheless, still some technical information is necessary. According to the inputs the toolbox provides possible strategies to implement, dividing them as high priority, to be done later or additional recommended.

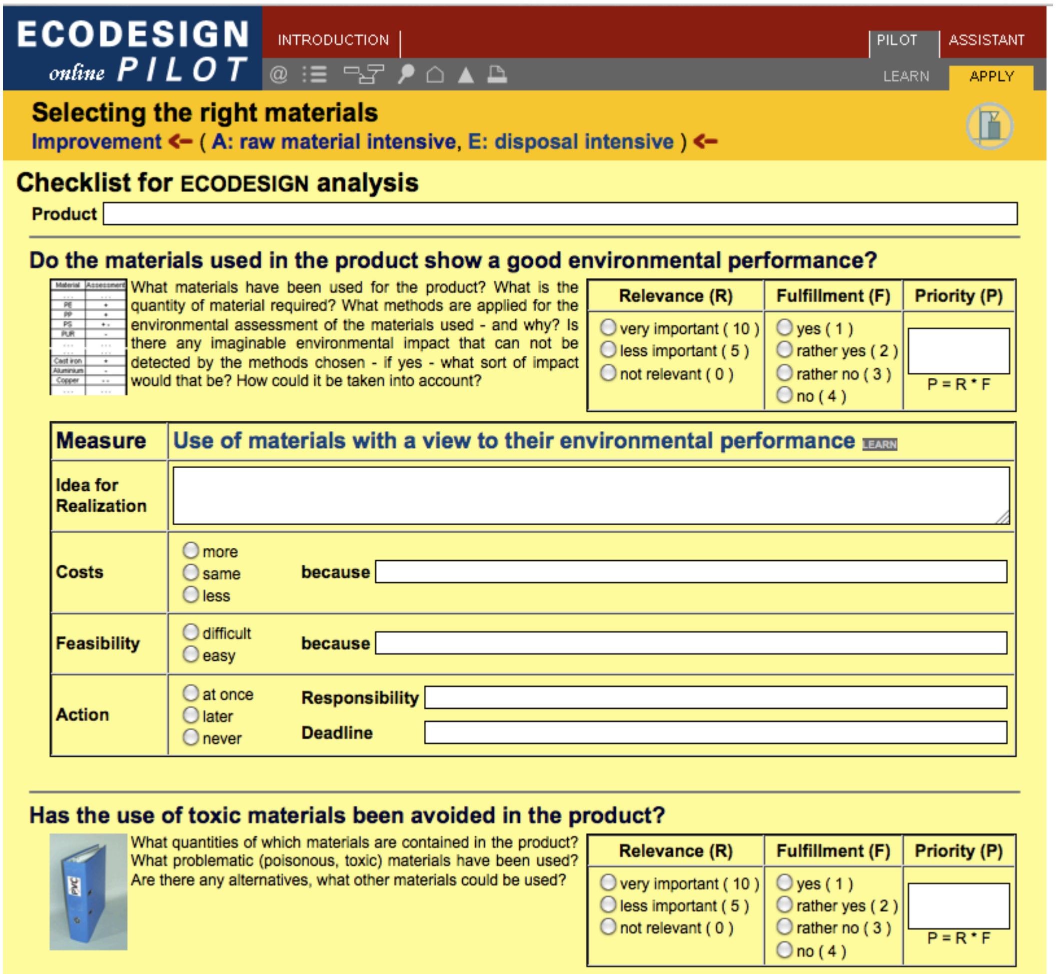

Fig. 2.43 PILOT data input screen, by TU Vienna

- ECO-LCA

  Ecologically based LCA, online and free tool “to account for the role of ecosystems goods and services”, created by the Process Systems Engineering Group at Ohio State University (2014). It has a large database of materials and manufacturing processes. The user must select the ones related to the project, from those selected information about material use and emissions can be visualised in bars, figure 2.44.

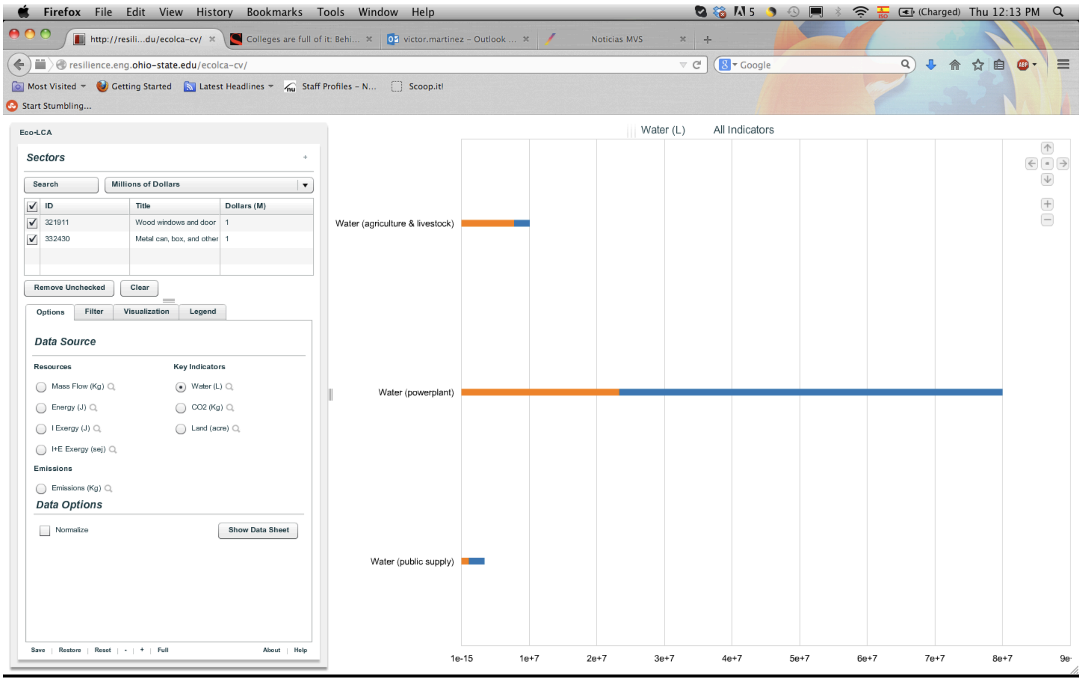

Fig. 2.44 ECO-LCA data search and input screen, by Ohio State University

A random order of selection is used, which has no reference whatsoever to a Life Cycle. It just provides just a final impact in general emissions, water usage, CO2 and land use, figure 2.45. It has a highly technical terminology. Information or options related to product use, transport and disposal are not considered.

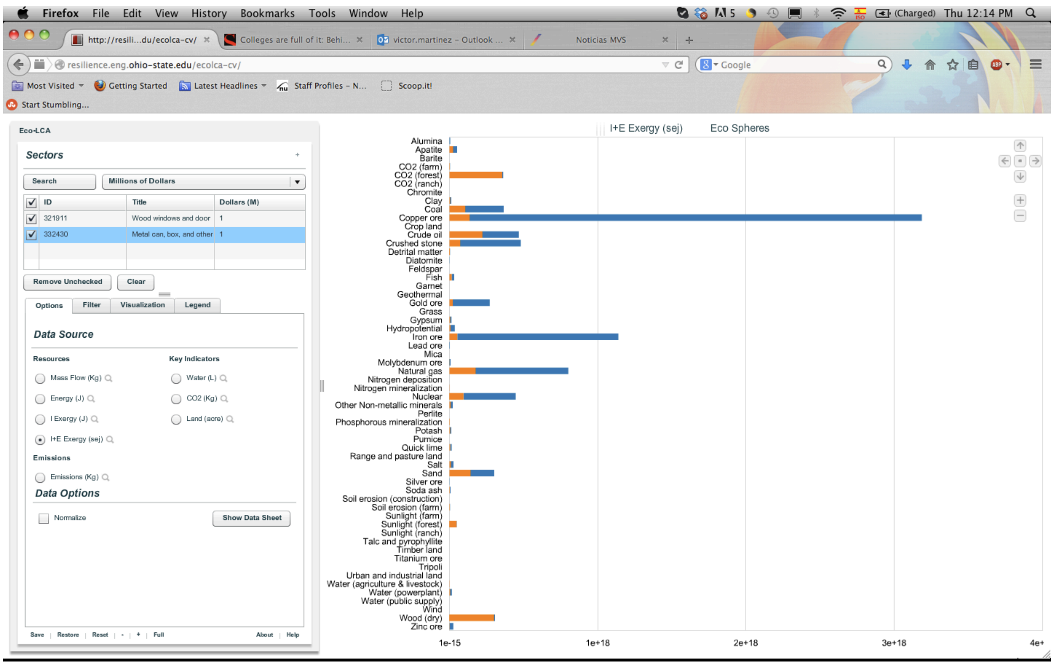

Fig. 2.45 ECO-LCA results screen, by Ohio State University

- Sourcemap

  Online software with the purpose of identifying the origins and connections between materials source, manufacturing and consumption of any given product, displayed in a world map (Sourcemap 2014). Each of these origins and connections are colour coded. The software is marketed for strategic planning and chain risk management, figure 2.46.

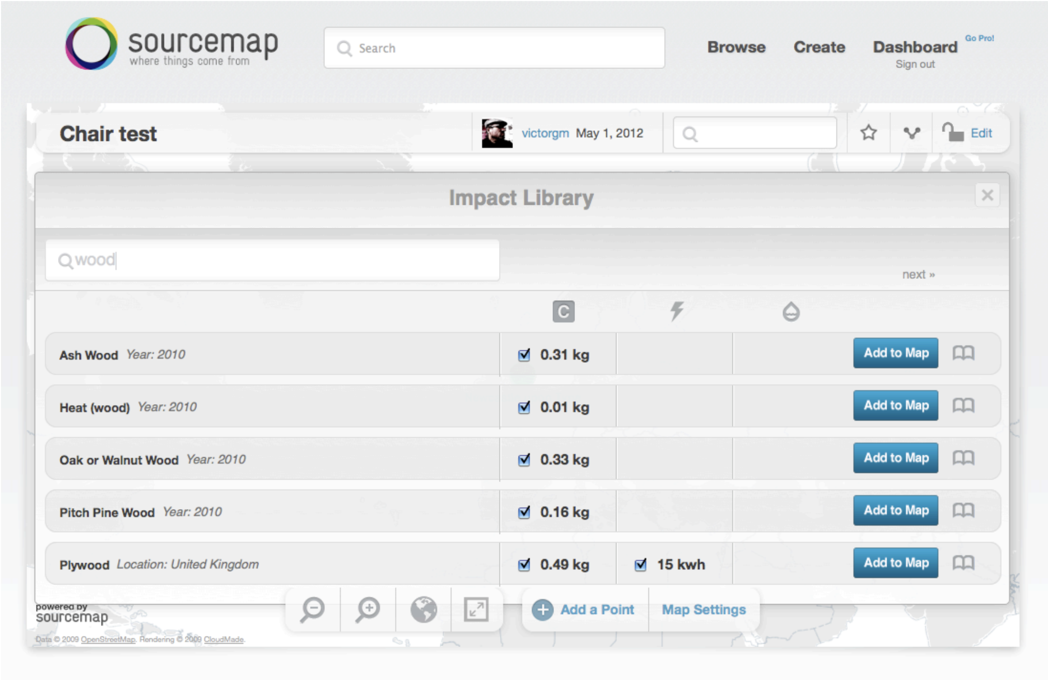

Fig. 2.46 Sourcemap data input screen

For each origin or connection the software provides certain information about providers and producers, or can be added manually by the user. By incorporating information about quantities of material, manufacturing processes and transportation methods the software provides CO2 foot print calculation and performance metrics, figure 2.47. A free version is available for students and academics.

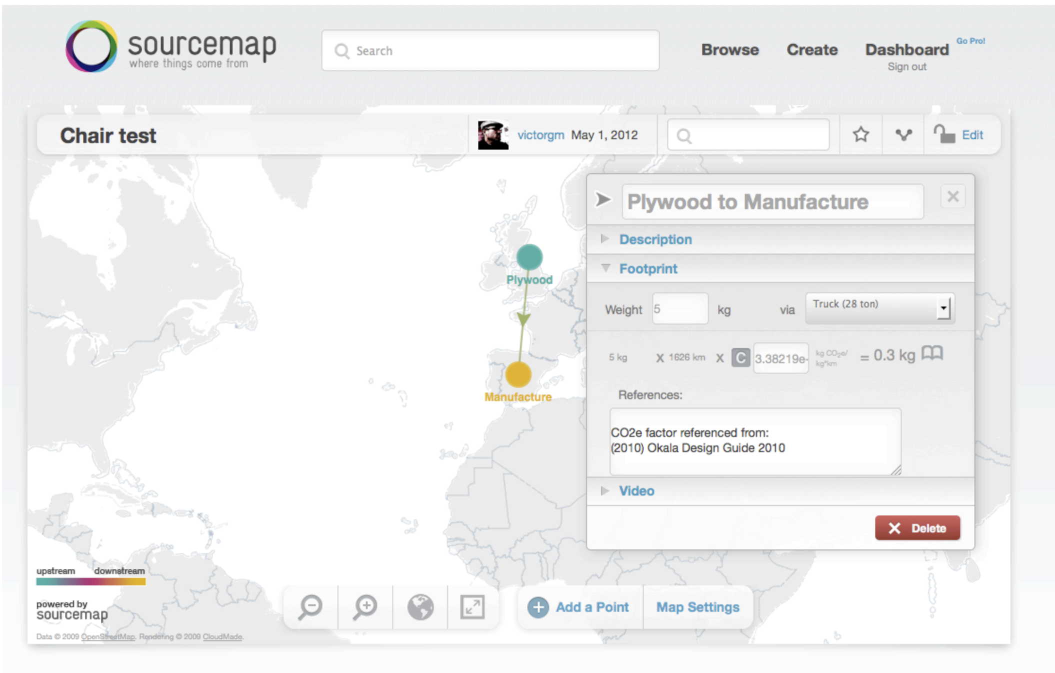

Fig. 2.47 Sourcemap world map and impact screen

- PIQET

Created by the Sustainable Packaging Alliance of Australia (SPAA 2014), PIQET is a web-based tool for packaging environmental impact assessments. It is oriented to optimise packaging system design from a sustainability perspective in all stages of product development process. In the form of drop down menus it provides material and transportation databases with the correspondent usage of electricity, gas and water usage, figure 2.48.

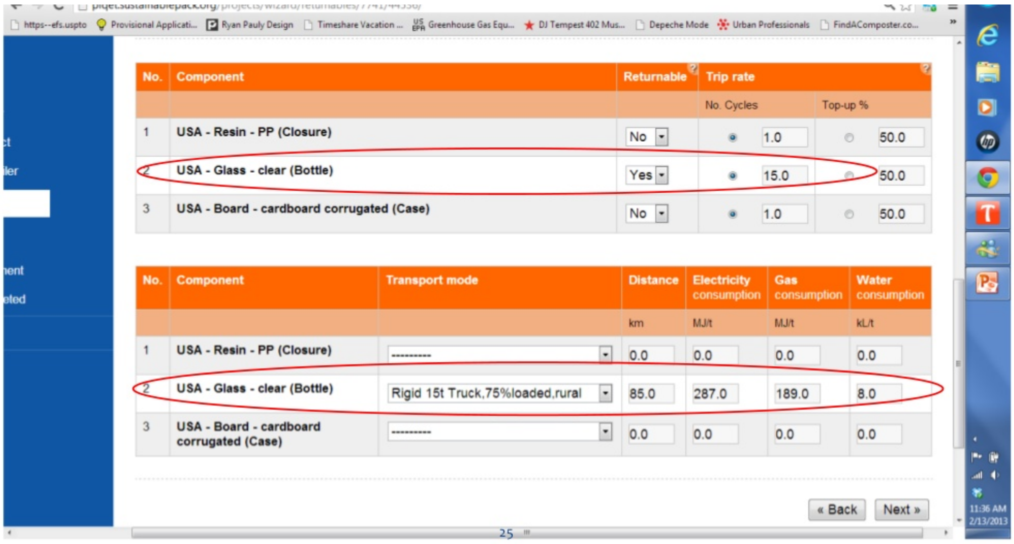

Fig. 2.48 PIQUET. Input data screen. Source: Slideshare user Pack2Sustain, LLC.

Interestingly it provides the option of creating different projects and assigning a "project owner" as well as team for the project. All this information can be shared throughout the company, results are displayed in bar graphics colour coded according to the source of the impact, figure 2.49.

Fig. 2.49 PIQUET. Result screen. Source: Slideshare user Pack2Sustain, LLC.

- ECO-it

  Made by the creators of SimaPro (Prè 2014), ECO-it is a tool developed specifically for designers as a 'simple tool' for 'their daily work'. By a series of tabs on top of the screen the Life Cycle steps can be accessed, each with one screen where to input variables about the description of the product and goals, as well as materials and manufacturing processes, usage characteristics and the percentage of the product will end up going to landfill, recycling, incineration or reuse, figure 2.50.

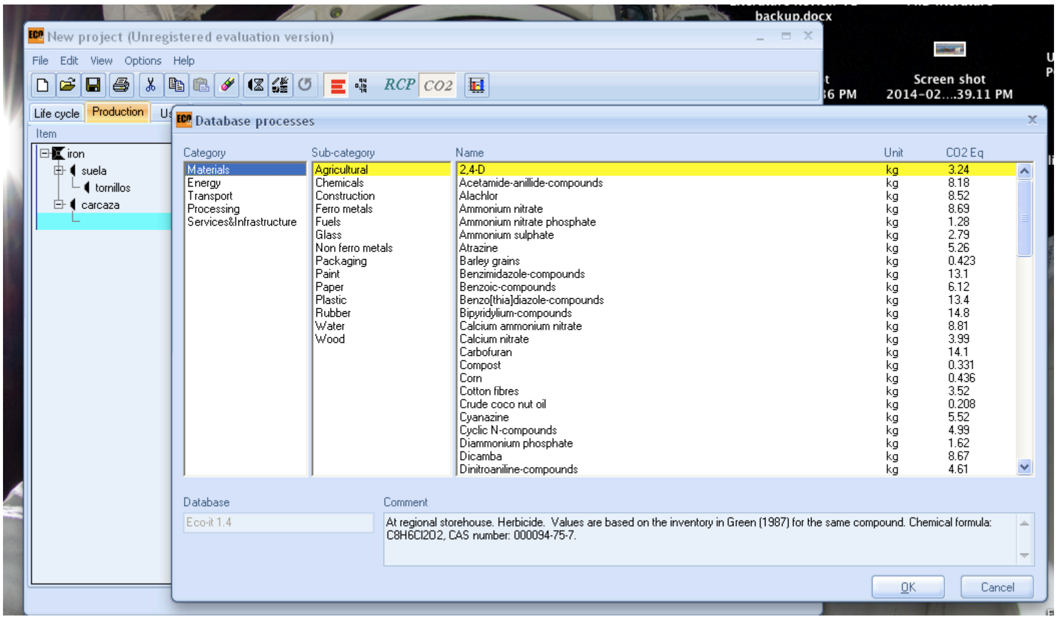

Fig. 2.50 ECO-it data input screen, by Pré

All these variables are selected through popup windows with very long lists of highly specialised information. At the end the inputs and results can be displayed in a pop up window in form of pie charts and bars, figure 2.51.

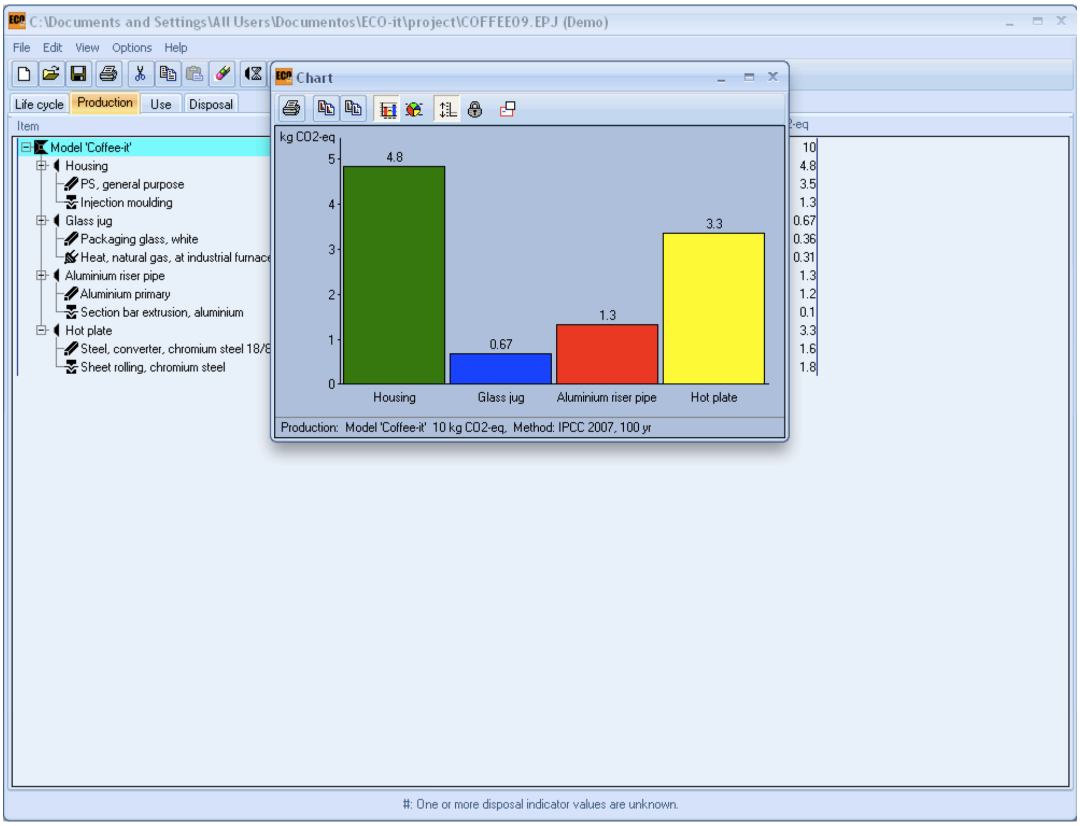

Fig. 2.51 ECO-it results screen, by Pré

- Making Nike

  Application developed specially for mobile devices (Apple OS only). It provides materials' information related to toxicity, energy intensity, water and land intensity, and physical waste, all based in Nike's Material Sustainability Index (Nike 2014). Quantitative and qualitative information has been translated into a system of points, where the designer can quickly identify what material is better, therefore Nike states that this application "educates designers to make informed real-time decisions about the impacts of their material choices", figure 2.52.

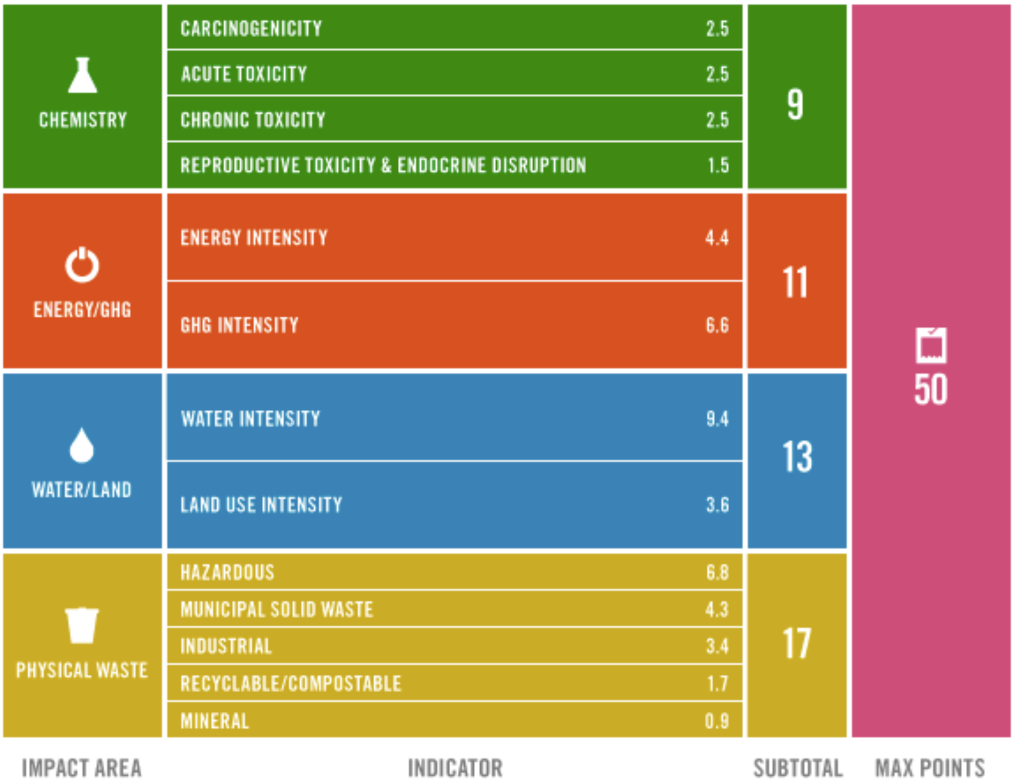

Fig. 2.52 Making App. Material Index, by Nike

All the impacts are colour coded and the use of simple graphics and low number of visual elements and practically no text makes it very easy to understand and use. It only covers the commonly used materials in apparel and footwear industry, figure 2.53.

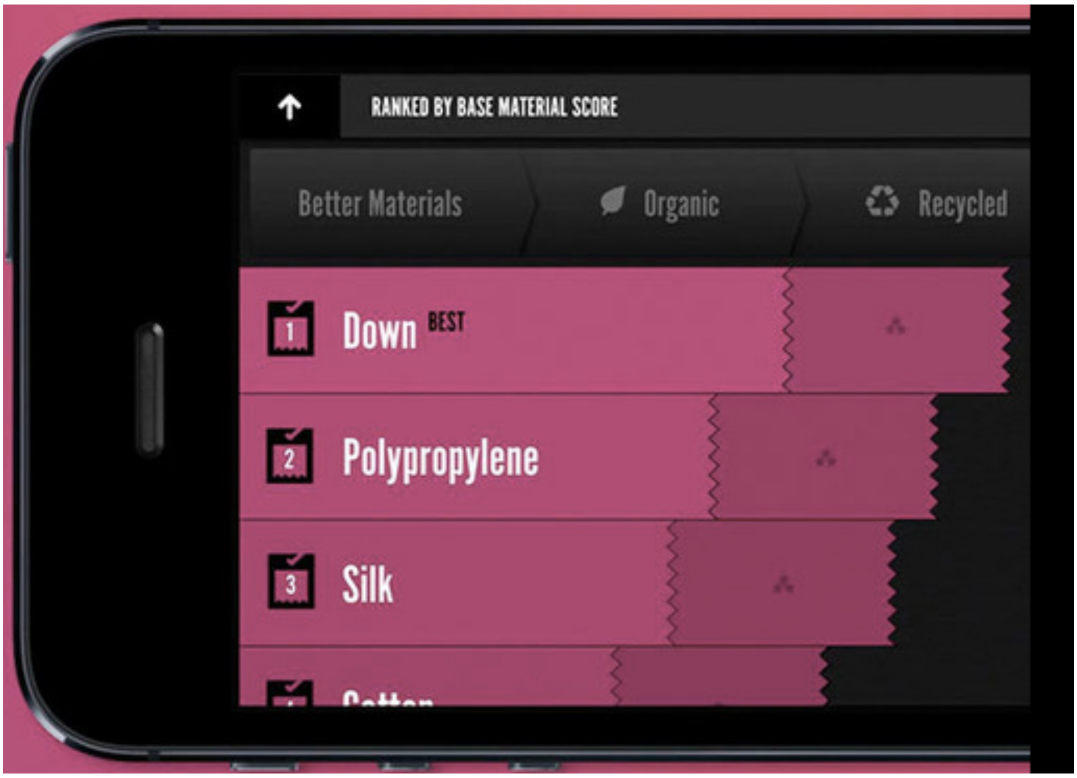

Fig. 2.53 Making App. Working screen, by Nike

- Myth busting Sustainability App.

  Created by Eco-innovators (2014) in Australia, this is an (only) iPhone app to 'overcome the persistent myths about sustainability', and this is done by using game design thinking. It is a "downtime" game with 50 multiple-choice questions, for each the app gives facts and figures as well as reference to web links and other information sources, figure 2.54.

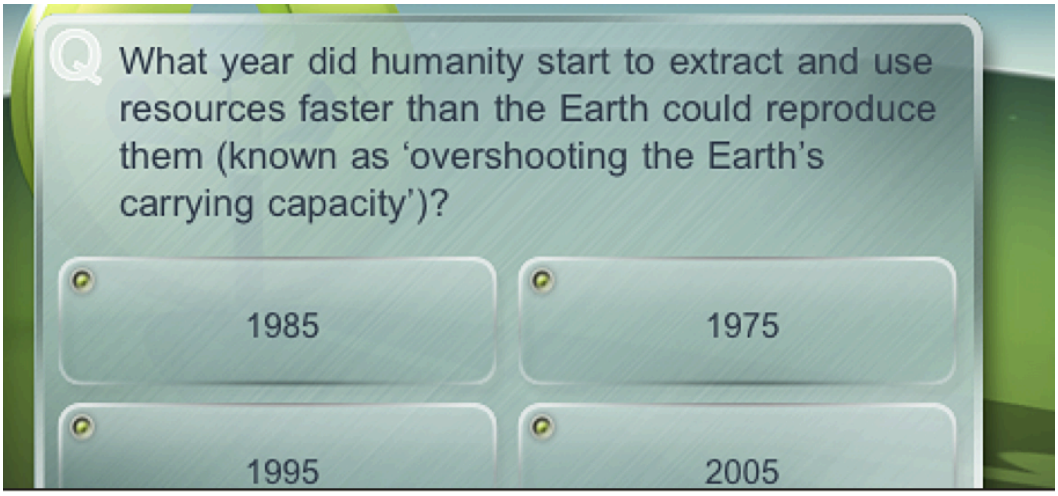

Fig. 2.54 Myth busting App. Screen shots, by Eco-innovators

For each question the user collects "items" and wins points. It contains large amounts of text and many visual elements; it has no clear relation or visualisation of the Life Cycle. This is aimed at general audiences and not specifically for designers, figure 2.55.

Fig. 2.55 Myth busting App. Screen shots, by Eco-innovators

- Greenfly

  Online life-cycle modeller with eco-design strategies 'for anyone involved in the development of products': designers, engineers, manufacturers, managers or marketers, created by the Centre for Design at RMIT University (2008). By entering information about the design concept materials, manufacturing processes and transport assumptions provides further information and evaluates the Life Cycle based on regulatory and compliance protocols. Tabs on the top of the screen accesses the Life Cycle steps, in each all variables can be assigned through popup windows, figure 2.56.

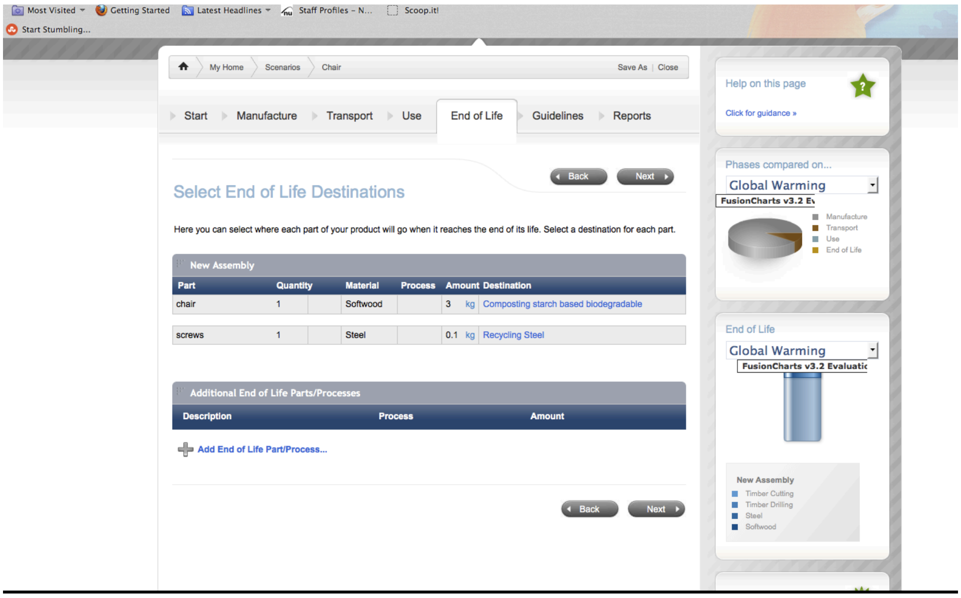

Fig. 2.56 Greenfly main working screen, by RMIT University et al.

The number of variables is large but not as large or specialised as the three first full LCA software presented in this analysis. For each variable some basic environmental considerations are presented. Results are always visible in pie charts and bars on the right side of the screen, and they change in real time and are colour coded accordingly to each Life Cycle step. In a new window it provides evaluations of global warming, water use, overall energy demand and solid waste by Life Cycle step, It also provides strategies and advice with higher and detailed information with fields where the user can write comments or actions to take.

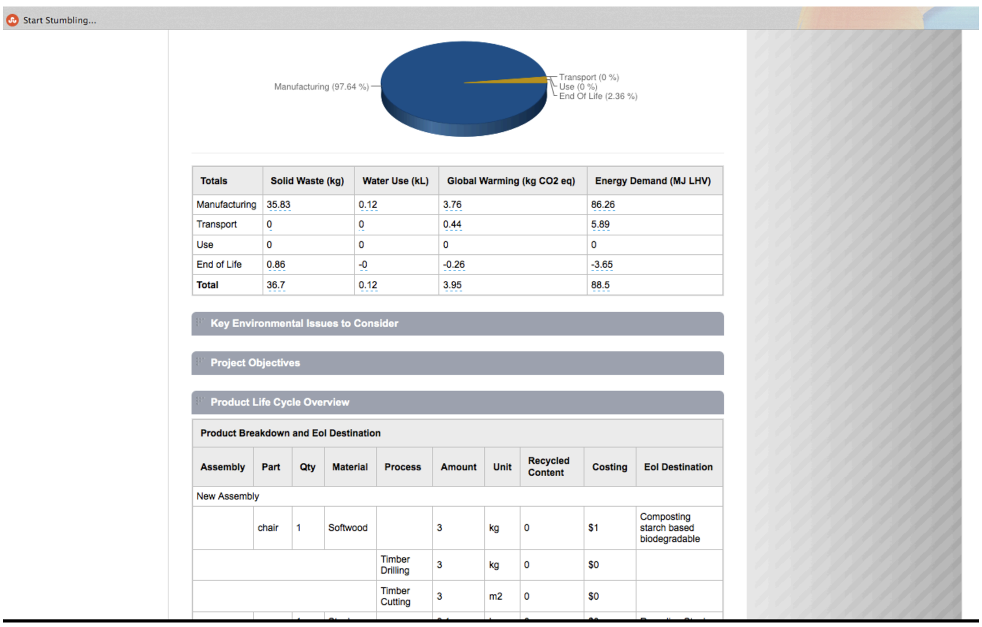

Fig. 2.57 Greenfly results screen, by RMIT University et al.

To summarise this review a series of characteristics identified in the tools are provided. These characteristics could be closer to the ideal for the working culture of designers at early stages:

- Large amount of information is to be avoided, as well as the exclusive use of text,
- Avoid the use of different screens,
- Variables can be presented in pop up windows as long as one element of reference is always visible - this could be the main screen as background or the steps of the process, which will also help the user to understand at what point her or she is, what is next and what are the different options,
- Appropriate use of colours and its combinations - code the information using these colours and if necessary with the use icons instead of words,
- Provide constant visualisation of the life cycle and make very explicit the possibility to close it when recycling/composting,
- Create the possibility to compare existing products and the concepts being developed,
- Avoid the need for expensive data sets; therefore use open source public information,
- Results should be always visible and graphically very simple, and change in real time,
- A second level of more detailed information should be available only when requested,
- Maintain a minimum number of elements visible all the time,
- Aid in identifying the challenge and provide the appropriate information and strategies to solve it.

In particular the tool developed by Nike was found to be of high interest and aligned to what a tool for designers at early stages might look like. The type of colours used and its coding with the information, minimum use of text, everything is visually very simple to digest and process. The use of a systems of points as and abstract way of representing the impact, rather than kilograms or W/h that are harder to rationalise, and lastly the possibility to be used in mobile devices.

2.7. - DESIGN PROCESS

“Design, as a problem-solving activity can never, by definition, yield the one right answer: it will always produce an infinite number of answers, ‘righter’, ‘wronger’, this will depend on the meaning with which we invest the arrangement”.
Victor Papanek (1985)

The way designers solve problems, in other words the design process, is probably the most researched theme in the design field. In this section the author will limit the analysis to the identification of the main structure of the design process and the characteristics of a design problem. This is because of the direct connection with the previously mentioned need to address new eco-design tools to each step of the design development, particularly in the early stages, and doing so coherently with the culture and requirements of designers. Examples of research methodologies and other characteristics related to the design process will be mentioned in the methodology chapter p.126.

Research in cognitive psychology has identified seven main steps for problem-solving cycle (Sternberg 2003), figure 2.58.

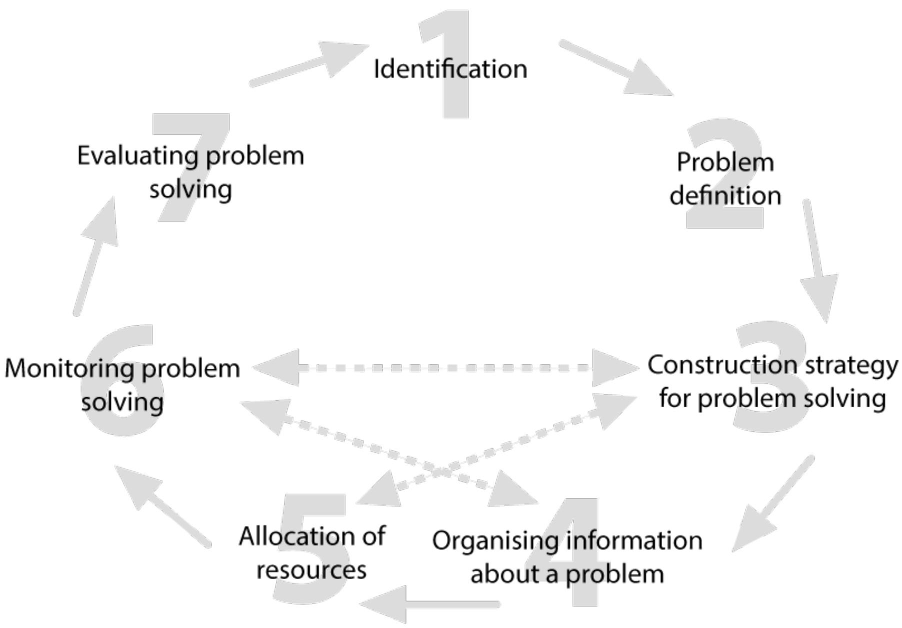

Fig. 2.58 Problem-solving cycle (Sternberg 2003).

Furthermore, it has been found that a combination of sensations, memories and thought processes give form to our attention, which therefore is composed of controlled processes (including consciousness), and automatic processes, which finally produces our actions (Sternberg 2003).

The limit of our working memory is key for the previously explained process, because it constrains us to considering just a few simultaneous operations with accuracy. Famously Miller (1956) proposed the maximum of seven actions at any one time, a phenomenon he called ‘span of absolute judgment’. Newell and Simon (1972) recognise it as the ‘most important mechanism’, capable of preventing the subject (or problem solver) from selecting an efficient strategy.

The above is therefore the precursor of our decision-making. Classical decision theory states that people will tend to maximise pleasure (positive utility), and minimise pain (negative utility) (Sternberg 2003). The previously mentioned work of Simon (1957) and his ‘bounded rationality’ theory, adds to this analysis the fact that people will seek to satisfy with a minimum possible number of options their minimum requirements.

The structure and contents of any given problem are mapped into what it is commonly called the problem space. Newell and Simon (1972) proposed a theory of information processing, in which a cognitive agent (or information processing system) with a problem is immersed in the ‘task environment’, primarily composed of the problem and the desired goal. All these build up the problem space in which the next structure can be identified (Goel 1995): it contains a state space, operators (allows to traverse the problem space, containing control functions (Goldschmidt 1997)), valuation functions (measure how close it is to the goal), control strategies (which guide the search), weak methods and a specific heuristic strategy: working forward, working backward, means-ends analysis and generate and test.

Setting the task environment is particularly crucial, because it is the process of searching beyond the individual problem and specifying the relevant external factors. However, in order to do this, it is necessary to have a criterion to discriminate between what matters and what does not. Goel and Pirolli (1989, 1992), identified the features of design task environment and a number of criteria, including the following; the availability of information: start and goal state; transformation functions; the nature of constrains, which can be nomological, dictated by natural law (hard non-negotiable) or social/political/legal/economic/etc (negotiable); the size and complexity of the problem; the component parts: structure of design problem is dictated by practice and experience of designer; the interconnectivity of parts: components are not logically interconnected and have many contingent interconnections; that there is no right or wrong answers: just satisfying for better or worse the goal state; the input/output: information about the users and artefact specification; a feedback loop: it has to be simulated; the cost of errors: penalties can be high; the independent function of the artefact (independent from designer); the distinction between specification and delivery (they normally differ); and a temporal separation between specification and delivery (causation).

Furthermore, Goel (1995) distinguishes twelve invariant features in all design problem spaces, from which, because of their relevance for this project, are highlighted the following four:

- Personal stopping rules: Because design problems do not have right or wrong answers, nor real-world feedback, these rules are derived from personal experience and immersion in the profession.
- Predominance of memory retrieval and non-demonstrative inference: there are few logical constrains, deductive inference plays minimal role.
- Reversing direction of transformation functions: designers can negotiate enlarge, narrow or change problem parameters.
- Modularity/decomposability: because size and complexity plus short-term memory, the problem is broken down, nevertheless connections between modules are mostly contingent, designers attends some and ignores others.

Lund (2003) states that problems can be catalogued under different perspectives, depending on the type of solution, or in the amount of knowledge previously required to solve it, commonly called knowledge-lean for those not requiring it, and knowledge-rich to those who do; domain general or domain specific, depending on the applicability of their solutions, non-adversarial or adversarial if there is competition involved in their solving (Lund, 2003). Finally well-structured and ill-structured under which design problems are normally categorised (Rittel and Webber 1984).

Well-structured problems are those in which the initial and final states are defined with precision before attempts to solve it are made. Information is only gathered at the initial state. The intermediate states do not increase our knowledge about the goal state and are controlled by known algorithms. It is just seen as match or no match, and it may have a finite and sometimes predetermined number of intermediate states (Simon 1984), figure 2.59.

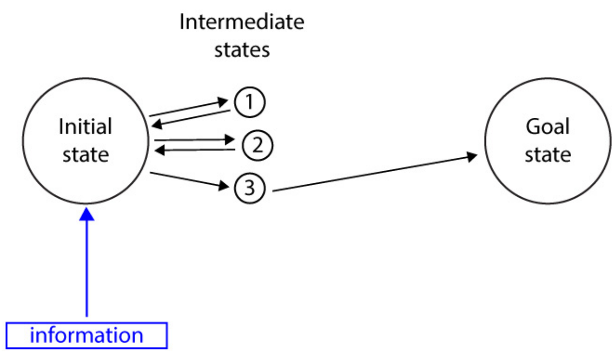

Fig. 2.59 Well-structured problem

In the case of ill-structured problems, the category under which most of design problems belong, the initial and goal states are vague or ‘partly determined’ (Dorst 2003). Many different goal states may satisfy the requirements defined at the initial state. Information not only modifies initial state, but also intermediate states, which therefore, are unpredictable in number and non-deterministic in character (Rittel and Webber 1984, Goel

1995, Goldschmidt 1997, Dorst 2003), figure 2.60. This differentiation of well and ill-structured problems, as a general approach is regularly accepted. Nevertheless, Simon (1984) argues that sometimes ill-structured problems can become well-structured during the process of 'preparation' by the problem solvers, which ultimately depends on the objective or subjective interpretative behaviour of the designer (Dorst 2003).

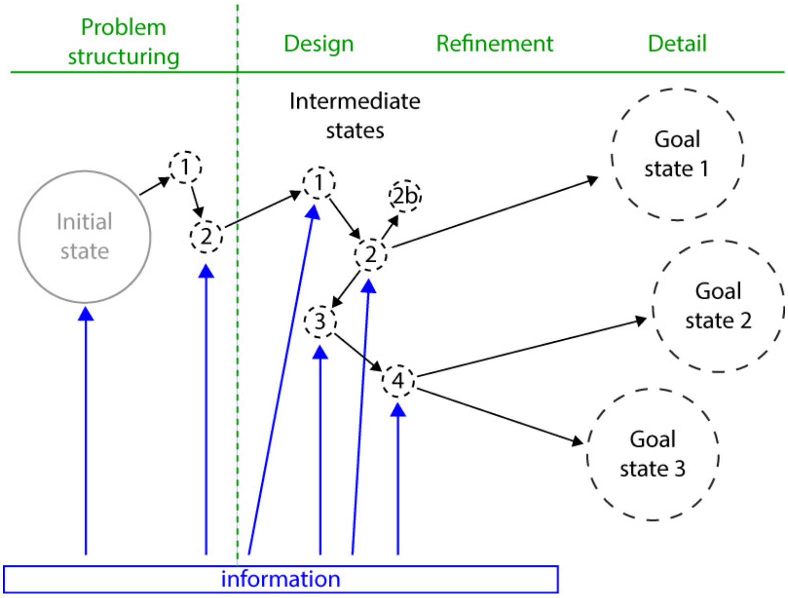

Fig. 2.60 Ill-structured problems, most of design problems belong to this category

Goel (1995) links each of the states of the problem, to a step in the design process. Problem-structuring occurs at the initial state, design belongs to the search of 'concepts' (potential solutions) in the form of intermediate states, with a constant and iterative analysis and synthesis (Dorst 2003). Refinement takes place when particular intermediate states are selected and are evolved closer to the goal state, and finally detailing the idea could be considered final exploration within the goal state. Goldschimdt (1997) refers to the movement from initial state to goal state as the 'problem solving', and proposes 'moves' - small steps in which reasoning evolves, and which consist of arguments with which problem-solver reasons.

The path designers take, and the speed in which they move from one step to the other differ greatly. These differences depend on training, personal preferences and style, how familiar they are with the task, and other similar factors (Goel 1995). Nevertheless, abstraction hierarchies have been identified, the type of information considered and the level of generality or detail in which it is covered are distinguishable throughout the design process steps (Goel 1995), figure 2.61.

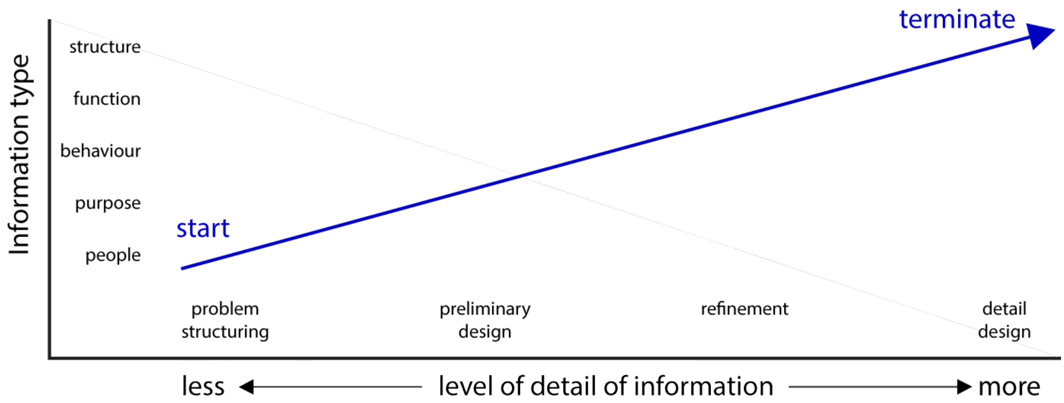

Fig. 2.61 Abstraction hierarchies (Goel 1995).

The classification of the design process in different steps or phases has been long studied. Many researchers have proposed a model and many of them differ greatly, from very broad and general steps (as few as three steps only), to highly specific and large in number (up to twelve steps); with also various degrees of complexity and technical terminologies. Notable is the work of Self (2011) and Howard et al (2008), which analysed several authors and proposed general categories in which similarities could be found. Figure 2.62 (p.92 and 93) presents a summary of some of the steps researchers refer to in the literature, highlighted with grey background is the one selected as reference for the experimental part of this project, which will be explained in detail in chapter 3 section 3.6 (p.116). Furthermore, this summary is correlated to the analytical tools reviewed previously in this chapter and the steps where they are normally used; this correlation is inspired by the work of Tishner (2001) and Vezzoli & Manzini (2008).

Greenfly	Myth busting	Making Nike	ECO-it	PIQET	Sourcemap	ECO-LCA	PILOT	SDO-LENS	EIO-LCA	LCA to go	S.Minds	Eco-Audit	Open LCA	LCA Calculator	GaBi	Umberto	SimaPro	Archer 1965 (in Self 2011)	Goel 1995	Baxter 1995 (in Self 2011)	Günter 1996	Lawson 2010	Martus & Maver (in Lawson 2010)
●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			- Business opportunity			
●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	- Programing - Data collection	- Problem structuring	- Design specification	- Clarifying the task	- Inception - Feasibility	
																		- Analysis	- Preliminary design	- Concept design	- Searching for concepts	- Outline proposals	- Outline proposals
		●									●							- Synthesis	- Refinement	- Embodiment design		- Scheme design	- Scheme design
●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	- Development	- Detail design	- Detail design	- Fixing the concept	- Detail design - Production information	- Detail design
●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	- Communica-tion				- Bills of quantities - Tender action - Project planning	
																				- Design for manufacture		- Operations - Completion	
																						- Feedback	

Fig. 2.62 Design process steps, according to different authors

Roy (in Self 2011)	Cross 2008	French (in Cross 2008)	Aspelund 2010	Ulrich & Eppinger (in Self 2011)	Self 2011	Cross 2011	Pugh (in Self 2011)	Design Council (in Self 2011)	Vallet et al. 2013
- Basic research & innovation		- Need	- Inpsiration						
		- Analysis of the problem - Statement of the problem	- Identification	- Planning	- Design specification	- Quantify the problem	- Specification - Formulation		- Goal - Initial assessment - Strategy
- Concept design	- Exploration	- Conceptual design	- Conceptuali-sation	- Concept development - Systems level design	- Concept design	- Generate concepts	- Conceptual design - Equates to specification	- Discover	- Solutions
	- Generation	- Selected schemes - Embodiment of schemes	- Exploration/ refinement	- Detail design	- Development design	- Refine concepts - Select a concept		- Define	- Assessment of solutions
- Prototype development & testing	- Evaluation	- Detailing	- Definition/ modelling	- Testing and refinement	- Detail design	- Design	- Detail design - Equates to specification	- Develop	- Decision
	- Communica-tion	- Working drawings	- Communi-cation			- Present		- Deliver	
- Final product or design engineering			- Production	- Production ramp-up			- Design completely in balance with specification		- Control

One more issue regarding how designers design, that is highly relevant to mention in this project, is how the designers' work-flow is expressed and captured. 'Part of the challenge to understand the design process, is the difficulty to clearly know what the designer is thinking; great part of the process is reflection-in-action' (Schön 1983).

The processes of decision-making, learning, and perception depend on the supposition of computation[2] (Fodor 2000), which in turn requires a system of internal representations (Newell and Simon 1972). There is yet no evidence of a symbol system for internal representations, but 'there is a close relationship between the structure of thoughts and the structure of our symbol systems' (Goel 1995).

It was mentioned previously that the movements between states consist of arguments on which the reasoning evolves (information processing system). These arguments (represented by symbols) can be figural or conceptual. They in turn can be both, internal and external, and also both, visual or verbal (Goldschmidt 1997).

We do not have evidence of internal representations because of our lack of methods to capture them. The closest we can reach today is brain activity, detected by devices like functional Magnetic Resonance Imaging (fRMI), and the correlation of certain areas of the brain with particular activities (Jung, Segall et al. 2010, Kaufman 2013). For the scope of this research project, attention will be focused exclusively on external representations. Verbal external representations are oral expressions, which include writing as a capturing method. Figural external representations are physical attributes of artefacts, such as forms and figures in drawings or models (Goldschmidt 1997).

External representations, both verbal and figural, are currently one of the only feasible medium researchers can count on to investigate what is happening during the design process. In particular the field of sketching is vast and complex as showed by Fish (1996), and the review produced in this document will attempt to provide only an overall perspective of the structure they have as a cognitive symbol system and how they relate to the design process phases.

Verbal representations can be easily captured by audio recording, and non-verbal by sketches or models, nevertheless it is the link between verbal and non-verbal external representations which is of higher relevance, as shown by Goel (1995) and Suwa et al (1998).

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[2] Computation from Latin *computare*: taking into account, to make calculation. Merrian-Webster (2014). English Dictionary, Encyclopaedia Britannica..

External non-verbal representations can be graphics in the form of sketches, drawings of any kind or models. Designers use them to manipulate representations of the world, instead of the world itself, and do it through many symbol systems, which in turn can be correlated with different problem-solving phases and cognitive processes (Goel 1995).

In the analysis of symbols systems (Goodman 1969), this correlation can be determined by means of:

- The syntactic criteria: a scheme in which all traces are perceptually different, but at least two particularities are similar, making them 'finitely differentiated' but not 'disjoint'.
- The semantic criteria: relates to the ambiguity of a layout, if it has different meanings in different times or contexts, which may result in different literal or metaphorical uses.
- Density: the amount of features which are dense, if between two there is a third providing infinitely ordered characters, but without necessarily deterring finite differentiation.
- Repleteness: a criterion for which a particularity of a layout is constitutive of it in that particular composition, or could be considered contingent. In repleteness little can be ruled out. The opposite is 'attenuated', figure 2.63 shows the relations between these concepts and a design project flow.

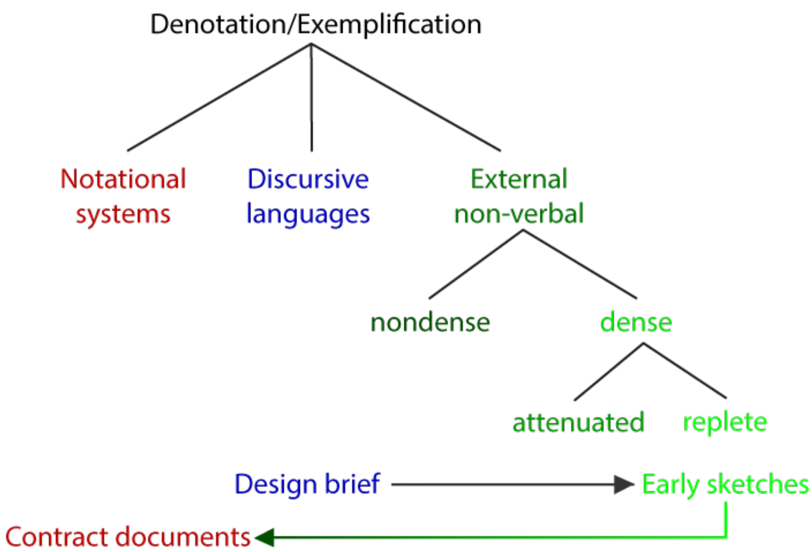


Fig. 2.63 Denotation and exemplification of symbols in a design project flow (Goel 1995).

Goel (1995) performed an interesting experiment where twelve experienced designers were given a one-hour problem solving session, using the think aloud method (which will be described in the next chapter), and video registering in order to capture the voice and hands, as well as computer activity (screen recording).

Using a coding scheme of his own invention, he distinguishes the origin of different episodes between being originated in the long-term memory, or related to the previous episode; and whether it was identical or a variation. He did the same with the sketches, whether it was new generation, or a transformation from the previous. He made two distinctions: lateral and vertical movements, the former as a variation but distinctly different drawing, and the latter as reinforcement through explication and detailing. It was found that sketches in early stages of design are more ambiguous and dense, which was beneficial for creativity, due to the different interpretation and generation of alternatives, as well as more lateral transformations were performed. The more progressed the work, the more detailed, specific and non-dense the sketches were with more vertical transformations.

Rodgers et al. (2000) used the concept sketches of 8 students to track their design progress along 15 weeks. Following Goel's findings on the increasing degree of concretisation and detail in sketches, they proposed a classification for the degree of complexity in sketches with a degree from 1 to 5, figure 2.64.

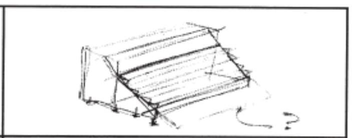
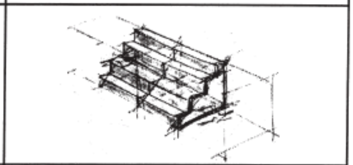
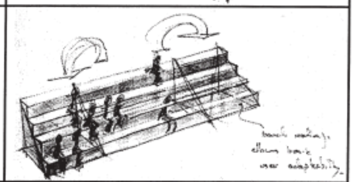
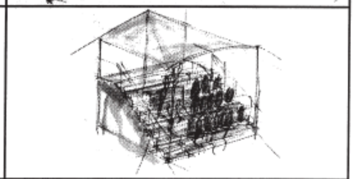
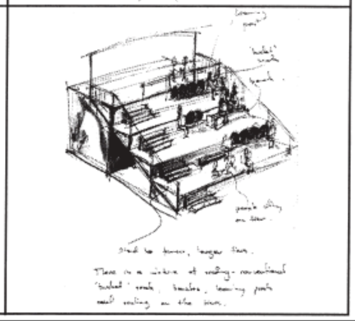
Complexity Level 1 Monochrome line drawing. No shading to suggest 3-D form. No text or numerical annotations are used.	
Complexity Level 2 Monochrome line drawing. There is no shading to suggest 3-D form, but there is use of different thicknesses of line. One or two brief annotations may appear, but not more than 6 or 7 words.	
Complexity Level 3 Monochrome, with rough shading used to give suggestion of 3-D form. The drawing may be annotated to describe certain aspects of the concept. May include dimensions.	
Complexity Level 4 Subtle shading is heavily suggestive of 3-D form. The drawing will almost certainly be annotated. Colour may be used to illustrate certain parts of the concept or arrangement.	
Complexity Level 5 Extensive use of shading to suggest 3-D form. Annotations will be used to ask questions of the idea or explain it. Colour will be heavily used. Generally a very busy drawing - many lines will be used in its construction.	

Fig. 2.64 Sketch complexity scale (Rodgers, Green et al. 2000).

Furthermore, it has been found the sketches' functionality as an external memory to be retrieved when needed, as 'visual cues' in order to associate designers' functions, and physical representations of the construction of functional thoughts (Suwa, Purcell et al. 1998). Goldschmidt (1991), elegantly defines them as 'pictorial reasoning' when arguing that they are not mere representations of internal images, but rather part of a dialectic 'oscillation of arguments'.

Many other researchers have analysed sketches and their function in the design process (Purcell and Gero 1998, Seitamaa-Hakkarainen and Hakkarainen 2000, Kavakli and Gero 2001, Schütze, Sachse et al. 2003) and how they can affect or support creativity (van der Lugt 2005, Yang 2008), as well as in identifying designers' approaches and design strategies (Bar-Eli 2013), in analysing the differences between sketches done in 'classic' and digital media (Verstijnen, Hennessey et al. 1998, Garner 1999, Jonson 2002, Bilda and Demirkan 2003), or even if they are necessary or not, to successfully produce design proposals (Bilda, Gero et al. 2006).

A coding scheme developed by Goel and Pirolli (1992) uses the mix of verbalisations and sketches to identify several characteristics of the design process. Later work by McGown et al (1998), and Rodgers et al. (2000), proposed a method to determine the complexity of a sketch and permit a quantitative analysis. This complexity is a first approximation to quantify the level of 'ambiguity' that Goel (1995) determined as relevant for the creation of lateral transformations. This method was complemented by a technique to individuate the sketch's creation flow by drawing overlapping rectangles in each sketch, in this particular study, which was held during a 15 week period, the identification of each sketch was made by the observer retrospectively, therefore involving certain degrees of interpretation. Furthermore McGown et al (1998), proposed a formula to 'quantify the qualitative difference' of sketches, following Goel's 'density' as part of the characteristics in sketching that may lead to lateral transformations:

C = complexity of a sketch ($1 \leq c \leq 5$)

S = size factor of a sketch ($1 \leq s \leq 5$)

Ips = Information held in an individual sketch, where

Ips = $(C \cdot S)$

Size factor scale developed for an A3-size working sheet:

1. Thumbnail sketch up to 50 mm x 50 mm
2. Up to 100 mm x 100 mm
3. Up to 150 mm x 150 mm
4. Very large – up to an A4 page

5. Full page – drawing covers most of the A3

In recent research, Bar-Eli (2013) proposes a series of categories and characteristics for sketches, in order to identify the behaviour profile of designers. From her research she has individualised three profiles: realisation, learning, and designer/reflective, she does it by analysing six variables:

- Representational references: writing, sketching (detailed, spatial layout and abstract sketch) and writing and sketching (levels, and dimensions and labelled information).
- Sketching type: detailed sketch, abstract sketch and multi aspect.
- Variation of representational type: plan, section, perspective, detail, diagram and axonometric drawing.
- Reference to scale: sketch in scale and sketch not in scale.
- Scale representation: people, openings and furniture.
- Assessment: repetition and audition.

2.8. - DISCUSSION AND CONCLUSIONS

The introduction of this chapter reflected on a number of complex factors that relate to the idea of sustainability, and that constant change is at the core of it. The understanding that current patterns of production and consumption of goods are in an unsustainable path in the long term, forces to think on how the designers should modify their practice and adapt to new conditions. For this reason the design profession has responded vigorously to the sustainability challenge. For decades academics and practitioners have produced hundreds of tools and methods to help them with the task. Despite all these efforts, there is little evidence of its impact in practice, in the conclusions of section 2.5 (p.43) were exposed the two main constrains preventing designers to use eco-design tools, one being "external" which represents complex factors such as companies' culture or market demand, an the other being "internal", with factors such as designer's motivation, willingness, perception among others. This research will focus on the latter, in studying the designers' reactions and boundaries when exposed to new tool characteristics.

Furthermore, evidence was presented relating the high relevance of early stages of design to incorporate sustainability parameters, and how, surprisingly, there is a lack of support in terms of tools for doing so. Several researchers arrived at the same conclusion that 'eco-design' is more based in management, and integrating or assessing impacts in a technical dimension, which has led to a more incremental type of innovation instead of the more needed systemic one. Therefore, a review of the design process' characteristics and how designers express and capture that process was also made, this informs the methodologies to be used in the investigative section of this project in order to analyse the working processes of designers, and identify any possible influence of the tool developed also in this project that attempts to fill the void detected in this literature review.

2.9 - GAP IN KNOWLEDGE

The improvement in designers' support to incorporate sustainable design in their daily practice has many possible paths. Nevertheless, the outcomes of the literature review pointed to a potentially important and influential one, that of concentrating the study on the early stages of design. Important evidence was also found directing the author's attention towards the need of a tool specifically addressed for the early stages of design, which responded to the discussed cognitive characteristics and capacities of designers, and previous researchers' recommendations, which are summarised below in no particular order:

- Life cycle approach (Lindahl 2005, Ostad-Ahmad-Ghorabi and Wimmer 2005, Luttropp and Lagerstedt 2006, Bovea and Perez-Belis 2012)
- Provide full and simple life cycle visualisation (Ostad-Ahmad-Ghorabi, Sharma Purohit et al. 2011)
- Allow exploring possibilities of systemic change (Jones 2003)
- Creativity and strategic thinking (Sherwin 2000, Vallet, Eynard et al. 2013)
- Easy and rapid to learn and implement (Lindahl 2005, Lofthouse 2006, Luttropp and Lagerstedt 2006, Ostad-Ahmad-Ghorabi, Sharma Purohit et al. 2011, Bovea and Perez-Belis 2012)
- Simple structure, visual communication: graphics, colours, minimal text (Sherwin 2000, Lofthouse 2006)
- Concepts, no detailed information - 'soft information' (Sherwin 2000, Lindahl 2005, Shedroff 2009, Collado-Ruiz and Ostad-Ahmad-Ghorabi 2010)
- Allow multidisciplinary cooperation (Lindahl 2005, Ostad-Ahmad-Ghorabi, Sharma Purohit et al. 2011)
- Creative environment, respond to designers' culture and attitudes (Ostad-Ahmad-Ghorabi, Sharma Purohit et al. 2011, Self 2011, Vallet, Eynard et al. 2013)
- Not represent additional workload (Ostad-Ahmad-Ghorabi, Sharma Purohit et al. 2011)
- Avoid excessive information and data flow, but present appropriate level and type of information (Sherwin 2000, Lofthouse 2006, Collado-Ruiz and Ostad-Ahmad-Ghorabi 2010, Ostad-Ahmad-Ghorabi, Sharma Purohit et al. 2011, Self 2011)
- Combination of guidelines, education and information (Lofthouse 2006)
- Easy access (Lofthouse 2006)

- Level of ambiguity and transformational ability (Self 2011)
- Instructions carefully considered (Jones 2003, Lofthouse 2006)
- Integration into designers' process (Jones 2003, Lindahl 2005, Lofthouse 2006, Luttropp and Lagerstedt 2006, Ostad-Ahmad-Ghorabi, Sharma Purohit et al. 2011, Bovea and Perez-Belis 2012)
- Stimulate thinking (Sherwin 2000)

All the above provided the fundamentals for the design and creation of an online tool, referred to as a 'soft modelling' life cycle sketcher. The researcher had access to funding from Northumbria University, and used open databases from institutions like the World Bank, United Nations, International Energy Agency and the CIA's fact book. A document providing a detailed explanation about how the tool calculates and performs all its processes is available at the webpage hosting the soft modelling tool.

Chapter 3 – METHODS TO INVESTIGATE THE DESIGNER'S WORKING PROCESSES

3.1. – INTRODUCTION

The literature review chapter provided the key insights for the approach and focus of this research project. As mentioned previously, there is a specific lack of research and support related to the integration of sustainability concepts in early stages of design (section 2.5 p.46). Following the principles for sustainability, also previously discussed (section 2.2 p.30), and the identification in the work of other researchers of ideal characteristics for an eco-design tool for the early stages of design (section 2.9 p.99), a 'soft modelling' life cycle visualisation software was created, which led to the main research question this project produces:

How is the designer's working processes influenced or altered when sustainability-related information is presented in early stages of new product development, through means of an online "soft modelling" software (Trophec)?

Intrinsically this question requires the analysis of the design process. Therefore, in this chapter the literature review will be complemented with a review, and analysis of the principal methods utilised by previous research, in order to capture and analyse the designers' workflow. The analysis will concentrate on the think aloud method, which request the participant to verbalise its procedure while performing a design task. Later usually those verbalisations are segmented, and coded using one of multiple methods available. In the case of this research the segmentation and coding was identified as unnecessary, this issue will be detailed in chapter five and six. However, the advantages of data triangulation methods were found as potential aids, thereby complementing data with concurrent and retrospective analysis. Finally some techniques for data visualisation and interpretation will be considered.

The taxonomy of design research, as proposed by Cross (2006), identifies four categories. Firstly, design epistemology, which studies the 'designerly ways of knowing', this is the human ability of design and how people achieve it. Secondly, design praxiology, the study of the practices and processes of design, in which this project is interested. Thirdly, the strategies, the process, and the techniques and tools to support the designer's work. Lastly, the design phenomenology, interested in the form and configuration of artefacts, their materials and finishing embodying the design attributes. Crouch and Pearce (2012), discuss the concept of praxis in deeper detail, postulating that generally it refers to the way we do things, but it belongs to a close relationship between 'thinking about action and a way of acting on thought'. Schön (1983) distinguishes this as a reflection-in-action, 'our knowing is in our action'.

In order to capture and analyse this relation of thinking and making, design research uses methodologies like ethnography, narrative, case study and action research, which come from a long tradition in social research (Crouch and Pearce 2012). Their application, singularly or combined, enable researcher to properly inform about the lived experiences of individuals or groups related to the design practice, and the practice itself. For this research a similar approach has been taken. Designers evolve an individual working style and together with their own personality, education, knowledge and interest they practice in the field of design. Acknowledging this diversity of approaches, the methodologies use to analyse the design process must embrace this differences and the inherent uncertainty in it, and allow as much as possible a 'natural' environment for the investigative step.

3.2. - CAPTURING DESIGNERS' THINKING

The study of how designers work and think has been slow but steadily growing in design research (Cross 2006). The impossibility of knowing precisely what anyone is thinking has provoked the creation of a great number of approaches, ranging from philosophical to empirical methods. Particularly in design, the externalisations of the cognitive processes are key to draw any insights about the way designers make decisions and perform in general, therefore, methods of capturing these externalisations and relate them to the possible influence of the soft modelling tool are of interest to this research project. In particular methods that could capture if the tool influences in the integration of what Polanyi (1969) defined as 'subliminal' and 'marginal' clues, which he then describes as 'tacit knowledge', switching designer's perspective from the particulars to their theoretical coherence, in Polanyi's famous words: 'we know more than we can tell', but there seem to be the need of assistance in that integration, in highlighting the connections, and how can this be made explicit and communicable.

Some of these methods rely on basic observation. This normally takes place in a controlled environment, regularly for a short period of time, or in more 'natural' conditions, commonly in the designers' workplace, maybe lasting weeks or even several months. Normally, observations are captured in a log in the form of notes or sketches, or whenever possible, by audio or video recording in order to obtain deeper detail and review data as needed. The choice depends on the research aims, duration of test, resources available, and project's confidentiality and ethics clearance. Large amounts of data can make the process of analysis rather slow or sometimes simply non-actionable.

Having a limited exposure to the task, it is some times regarded therefore useful to 'triangulate' different sources of information (Creswell and Plano 2012), helping ensure accuracy in the information. Data can be compared to create better insights or simply to make results more robust. Complementary methods to observation often rely on self-report methods like surveys, questionnaires, interviews, and designers' own notes and sketches in analogue or digital media. Depending on the type of research and infrastructure available, triangulation can be further supported by other methods like heart rate and pupil dilatation measurement, or eye tracking. The final combination may deliver data in qualitative and quantitative form (Martin and Hanington 2012).

Cross (2006), summarises the research methods applied to understand the nature of design thinking:

- Interviews with designers (normally performed with experienced designers, usually through unstructured interviews, in order to capture designer's reflections on the process and procedures).
- Observation and case studies (on one particular design project at a time, with current real projects, re-creations of past ones, or completely artificial ones).
- Protocol studies (thinking aloud and associated actions, applied to artificial projects with experienced designers or students).
- Reflection and theorising (theoretical analysis).
- Simulation trials (simulate human thinking in artificial intelligence).

Nevertheless the one considered as a 'formal method… and perhaps the only method' capable of uncovering the cognitive abilities of designers (Cross 2006), and providing the most robust and insightful results in design research, has been protocol analysis (Ericsson and Simon 1980). Protocol analysis is based on the think aloud technique, as an example are a series of key studies by more than 40 researchers based on this method, which was compiled by Cross et al (1996). In their study, Chai and Xiao (2012) found that this method is one of the most commonly used in design research.

Think aloud is nothing but the verbal account of a subject's own cognitive activities. First appearing in the early 20th century in psychological research (van Someren, Barnard et al. 1994, Cross, Christiaans et al. 1996), it was not until the invention of recording machines that it was more broadly used, due to the need of capturing the subject's verbal expressions for analysis.

In the 60s and 70s it gained popularity, mainly due to the work of Newell and Simon (1972), which used think aloud protocols together with computer models of problem solving processes, in order to produce models of internal cognitive processes. It was not until the 70s in the pioneering work of Eastman (1970) that was first used by architecture and later in the design field. Since then has provided important results, but not without some unsolved issues. The intrinsic characteristics of design problems make the think aloud method very hard to draw general comparisons, and there is no agreement relating standards or procedures for the studies, as Perry and Krippendorff (2013) have exposed. There have also been some other disturbances in the cognitive process due to the verbalisation, like incomplete accounts or irrelevant accounts of 'parallel independent thoughts' (Lloyd, Lawson et al. 1995, Cross, Christiaans et al. 1996).

Nevertheless van Someren et al. (1994) provide some general guidelines on how to perform a think aloud session. Think aloud broadly means that the participant verbalises, during a problem-solving task, all his or her thinking, reflections and understanding of the situation; the participant should speak out loud any thoughts coming to his/her mind. Any interruptions or suggestive prompts should be avoided as much as possible, in order to deter the participant from interpreting or explaining what he/she is doing; it must deliver a 'concurrent account of his/her thoughts'.

The task of speaking the thoughts out loud is not considered difficult, and most people become familiarized with it quite quickly (Cross, Christiaans et al. 1996). This is due to effort being concentrated in solving the problem, and not allowing room for the verbalisation of reflections of what they are doing. Thinking aloud does not generally obstruct the performance (Ericsson and Simon 1980). The information that can be verbalised is drawn directly from the working memory, all long term memories first have to be retrieved before they can be verbalised, therefore through this method it is possible to have a close realisation of the structure of the thinking process, the strategies adopted, and how the ideas were built, their flow and the reasoning behind decisions (van Someren, Barnard et al. 1994).

There are some other factors that could compromise the validity and completeness of verbal data according to van Someren et al (1994): invalidity due to disturbance of the cognitive process (in some cases from interruptions), incompleteness from memory errors (essentially not present in think aloud), incompleteness or inaccuracy from interpretation by the participant (think aloud protocols can be very accurate).

Particularly in think aloud protocols the cognitive processes take longer, because both activities of verbalisation and building thoughts are performed concurrently, leading to problems of synchronisation in data. Participants sometimes report that their verbalisation does not follow at the same time with the cognitive process, giving therefore incomplete or inaccurate reports. This can be seen as 'holes' in the protocols, in which the researcher must assume that an intermediate thought took place (van Someren, Barnard et al. 1994), even more, Csikszentmihalyi (1996) through his theory of 'flow', describes how designers are not able to be creative and make a rational verbalisation of the process contemporaneously. It is for this reason that sketching, as a parallel activity of cognitive process, is highly relevant in protocol analysis (Cross, Christiaans et al. 1996).

Other situations may present a different challenge, if, for example, reasoning comes in nonverbal form and in a complicated structure, verbalisation will require space in the working memory, making the process part of the cognitive process itself. This again may result in incomplete reports and even disruptions in the process (van Someren, Barnard et al. 1994).

3.3. - PARTICIPANT, TASK AND SETTING SELECTION

One of the first considerations is to minimise disruptions of any kind during the test sessions. Regarding the design task participants will work on, it is important to consider that overload of information may cause synchronisation problems. Therefore the difficulty, and the expertise of the participants should be carefully considered against the research aims and objectives. Normally, the access researchers have to participants is very limited, and so the variables to bear in mind regarding this are the level of expertise and verbalisation skills. In this sense, it is evidently desirable to have high verbalisation skills, but depending on the limited access and the sample needed, researchers' often do not have much choice (van Someren, Barnard et al. 1994).

It is well known that designers tend to be solution-led, and not problem-led (Kruger and Cross 2006). Therefore, even when constrains and goals may be known, designers tend to change them and introduce new ones from their domain knowledge (Cross 2006), which makes the task selection a particularly important one.

Two fundamental questions have to be analysed before selecting participants and task (van Someren, Barnard et al. 1994):

- Is the task at a level of difficulty that is appropriate for the subjects with respect to the cognitive process?
- Is the task representative with respect to the cognitive process involved?

Settings must make the participants feel relaxed; the room should be quiet and a glass of water at hand. As previously mentioned, the researcher should interfere as little as possible, but an explanation about the purpose of the research and how the data will be handled is needed (van Someren, Barnard et al. 1994).

Once all preparations are made for the test, and with the instructions at hand, the central point should be to perform the task requesting the participant to say out loud what comes to mind. It is good practice to have all instructions written in advance, and phrases like 'tell me what you think' should be avoided. This is because the participant may feel obliged to give their opinion, giving way to an evaluation and reasoning of the process that should be avoided. Instructions should not be too long, also to avoid the participants making their own interpretations about the test. Before starting the test, an exercise could be made to practise the thinking aloud, taking just a few minutes (van Someren, Barnard et al. 1994).

The researcher should restrain from making comments, intervening with 'keep on talking' only if the subject stops talking. General recommendations about the recording are to double-check all instruments before and during the session. Once the test is finished, good practice is to review the protocol with the participant as soon as possible, with any additional comments and explanations not considered part of the think aloud, just complementary data in the form of retrospective analysis (van Someren, Barnard et al. 1994).

The next activity is to transcribe the protocol, typing all contents as verbatim as possible. Researchers must assume for this procedure to require up to ten times longer than the original protocol. This will depend on the clarity of the recording and the fluency of the participants, such as particular accents, mumbling or not finishing words or phrases. In the instances where is not possible to understand what has been said, a note of 'unintelligible' should be made. All events should be considered on the transcription, such as asking for water, comments about the weather, session interruptions, etc. It is highly relevant to know what happened because may cause changes in the problem-solving process (van Someren, Barnard et al. 1994).

The transcribed protocol is then segmented; this is normally done by the pauses on the participant's phrases (Ericsson and Simon 1980), which in its combination, and the speech structure itself, gives a natural way for creating segments. These segments are later coded in schemes identifying actions and organising them into categories (van Someren, Barnard et al. 1994), being dependent on the coding technique, which will be analysed next.

The thinking aloud protocol is regularly considered to be an individual task. However, there are examples and arguments regarding the natural dialogues in teams and if these should be considered under similar terms (Goldschmidt 1995, Radcliffe 1996). Perry and Krippendorff (2013) report several research projects where teams have been the subjects of think aloud protocols. There is nevertheless clear evidence that teamwork is a social process, and in protocol analysis of teams, the social interactions, roles and relationships should always be considered (Cross and Clayburn 1996). Broader research on the role of dialogues in design practice have revealed its relevance to 'clarify, explain, interpret, assess, argue, and engage in iterative levels of reflection and critique' (Oak 2011).

3.4. - MIXED METHODS

Creswell and Plano (2012) explain the idea of mixing methods in research as the triangulations of sources, with the goal of convergence to corroborate and find correspondences in results. The complementarities achieved by this enhance, clarifies, and illustrates the overall results.

There are many possibilities for mixing and complementing data. One example could be the notes taken by the researcher, or video recording of a problem-solving process, which could be revisited by the participant, thus triggering further analysis and reflection. This type of retrospection can provide useful insights that would not be reconstructed otherwise (van Someren, Barnard et al. 1994). This type of self-report is sometimes criticised for obtaining data, which may lack accuracy, but helping the participant remember thoughts, particularly directly after the test, can minimise this issue.

This lack of accuracy is caused because retrospective analysis may provoke participants to 'present their thought processes as more coherent and intelligent than they originally were' (van Someren, Barnard et al. 1994). Retrospection requires retrieving and then verbalising information from the long-term memory, creating a disadvantage if not all the information that took place in the problem-solving task is retrieved, or even if part of that information did not belong to that process, but is retrieved from other sources in the long-term memory.

In a think aloud test incomprehensible, incomplete or odd dialogues may block the possibility of constructing a model of the cognitive process. Nevertheless this could be clarified by observing the participant gestures or sketching, and furthermore with the above-mentioned retrospective self-report supported by notes or video, especially if it is done directly after the session.

Furthermore, the combination of qualitative data, which aims for understanding how the context is experienced and to gain deeper focus, with quantitative data, which allows objective numerical ways to answer questions, can provide relevant insights. Therefore, multiple data sources and ways of presenting them, is crucial to enhance reflection in the researcher (Crouch and Pearce 2012).

Lastly, computer usage, and particularly the internet as an information source, has become an essential part of the designer's working process, and therefore a potential area of research, especially if accounted as another data source for a mixed methods approach. Cash et al (2013) found in their literature review that the internet is the second most important source of information in engineering design, and the primary is the engineers' own working documents. Other sources include people's own business group, and personal memory.

In the literature related to eco-design tools testing and analysis there was not a detailed description of the methods used to capture the participants' actions, there are mentions of questionnaires and surveys among others; nevertheless there is in this research an uncertainty in relation to in what form the effects of using a new eco-design tool may appear during the designers working processes. Is for that reason that a mixed approach becomes highly relevant, acknowledging that at some point some methods will be rendered inadequate. One more point is the correlation of the different data sources, and for that reason a unison visual representation of all data sources is proposed in order to analyse and identify the effects of the tool's usage.

At this point, adding the findings in the literature review and the methods discussed the series of effects that can be expected when designers are exposed to the tool are:

- In the case of the verbalisations longer than usual pauses or clear statements of confusion or regression in the process could represent evidence of the tools effect in the working process.
- In the case of sketches it was shown how there is a correlation between sketch complexity and density to the progression in the design process, having more complex more defined, larger and less in quantity at the end of the process, therefore a possible effect of the tool would be the return to less complex and greater number of sketches.
- The presence of lateral or vertical transformations could provide similar evidence of a regression in the process or stagnation.
- Concurrent reports, pre-test and post-test surveys may give some impressions of the designers' thinking regarding the tool and the design process as well as a final interview.

All this data sources could potentially be sources of evidence and visually representing them in order to also find potential correlations hasn't been found in literature as it is proposed here, therefore an interesting opportunity for this research, next are presented some relevant visualisation methods so far identified.

3.5. - DATA VISUALISATION OF DESIGN PROTOCOLS

The protocol analyses using the think aloud method found in literature were between one hour and six hours in duration. Nevertheless the volume of data is very high, and time consuming to process. Therefore, just a fraction of the entire protocol is regularly selected, ranging from one or two minutes for highly detailed analysis, up to 30 minutes.

In order to communicate the characteristics of the process and findings, researchers have produced different data visualisations. There are many examples, some highlighting the relation between verbalisations and other features of the process, like sketches, others allowing a visualisation of the 'flow' of the process along time. Outlined below are some samples, from which this research has taken inspiration.

Nevertheless, these visualisations have been developed to communicate findings of specific research goals. The author did not identify any visualisation that combines them, or added multiple elements of the design process, which in their complexity could be interconnected, and may show patterns or highlight relations of phenomena not yet discovered. As it is known that is easier to process complex structures visually rather than relying on working memory (Ware 2004).

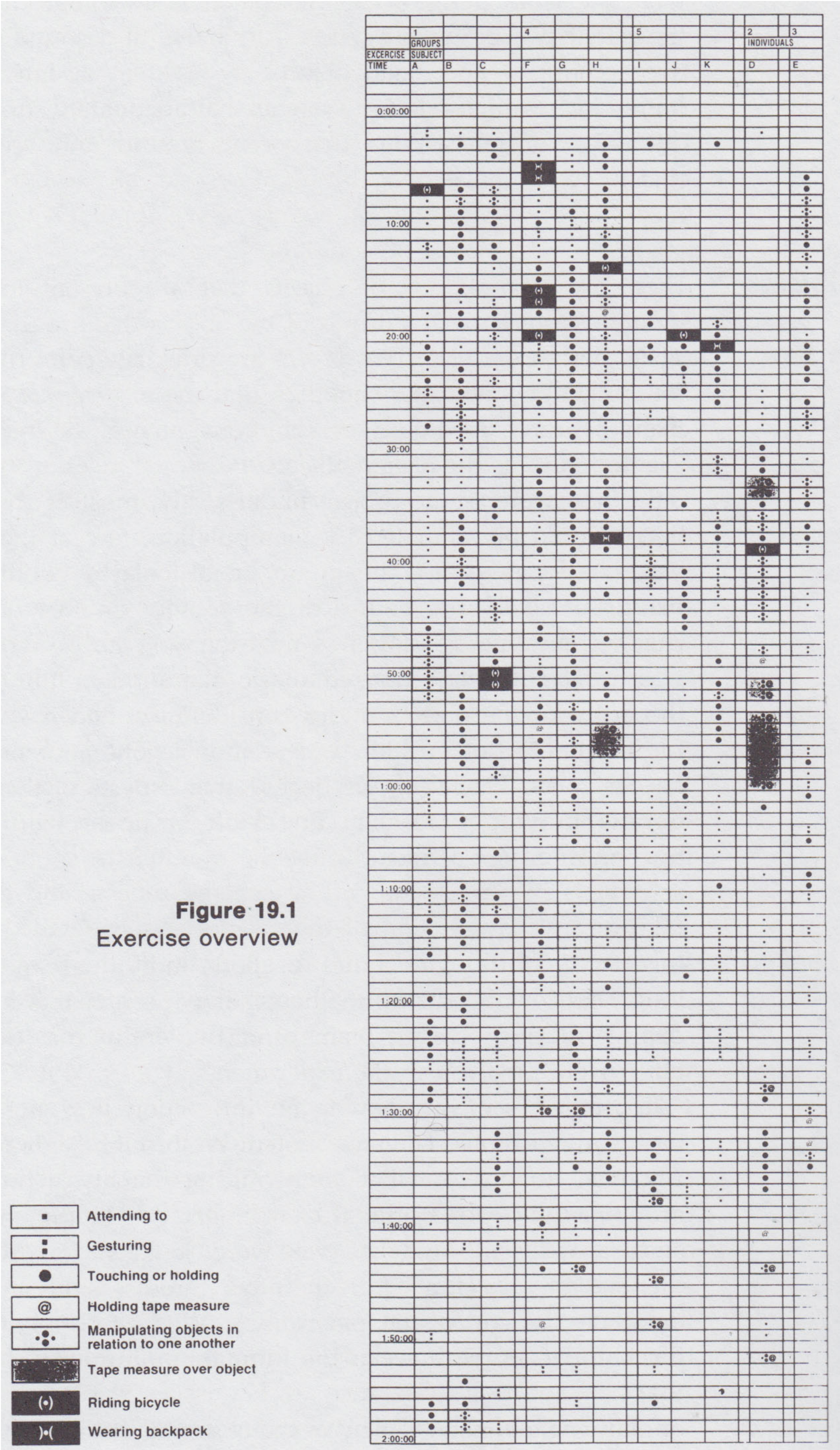


Fig. 3.1 Harrison and Minneman (1996) were interested in highlighting the interaction with physical objects during a design session, they first identified the segments of a two-hour session in which designers interacted with objects, and divided those segments in blocks of six minutes, afterwards they coded the activities depending on the type of interaction with the object. There is no relation with dialogue nor how these interactions affected or influenced sketch creation or other processes. It was used on three sets of three participants and two individuals. Each column represents one participant.

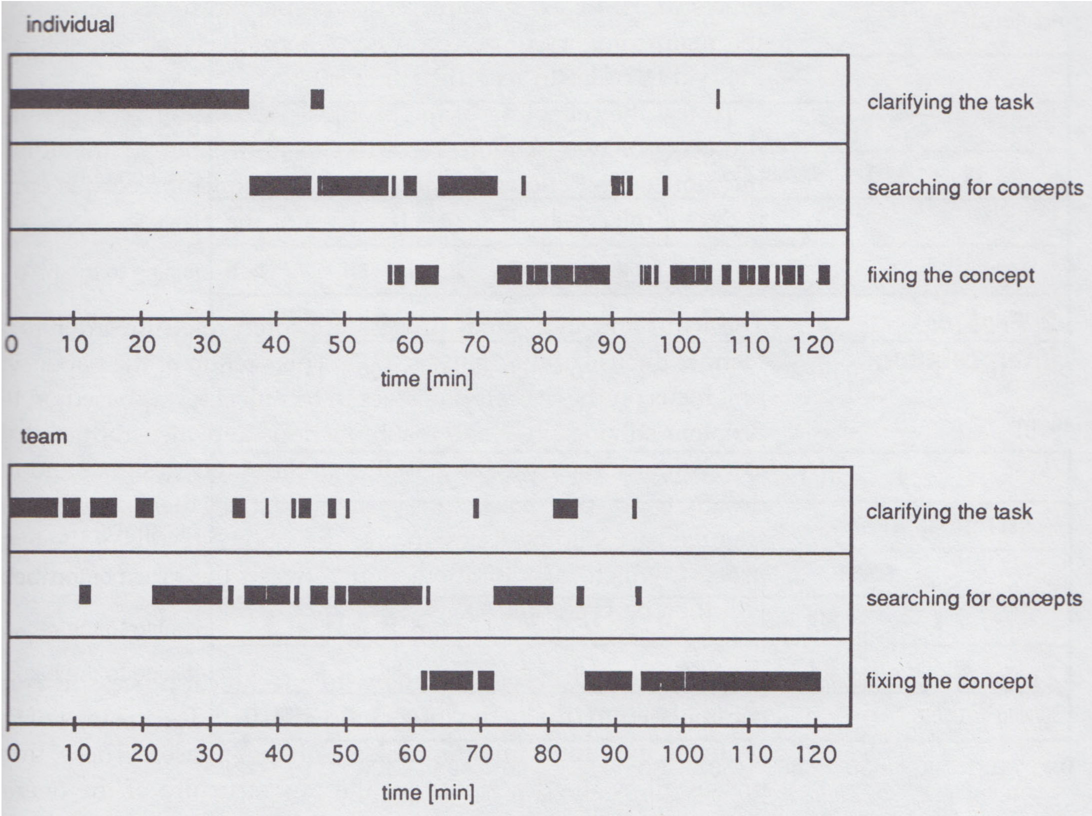


Fig. 3.2 Gunther et al (1996), demonstrated their method of record-keeping and interpretation, they were interested in describing the technical development of the solution and the social processes. For the technical perspective they identified designers' activity within three different steps of the design process, the visualisation shows the allocation of time for each one of them. It can be clearly seen the progress of designers' workflow and the non-linearity of it, especially in the team (bottom). There is no visual correlation with dialogue or sketching. In this case a two-hour long test was analysed entirely and performed with one team (bottom) and one individual (top).

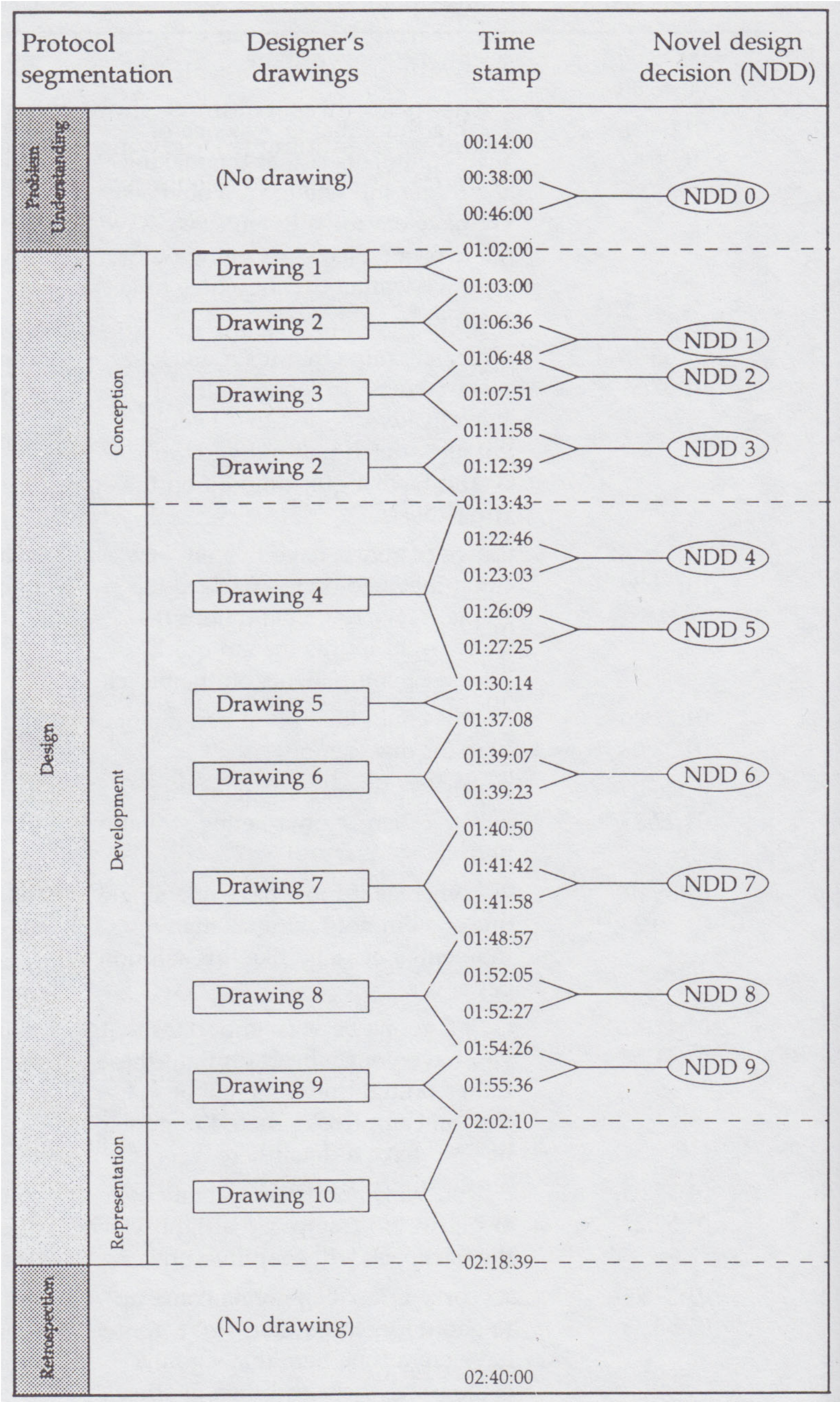


Fig. 3.3 Akin and Lin (1996), studied the features in a design process that give raise to what they call 'Novel Design Decisions', for doing so they analysed and correlated: the design steps, sketches, dialogue and activities such as drawing, writing, thinking, examining, listening and speaking. In this visualisation they show the time allocated by designers in five different design process steps, the sequence of sketches creation and the time designers used to create them, the moment of 'Novel Design Decisions' (NDD). It presents the process as linear, and the sketches creation is not visualised proportional to time scale, nor correlation with dialogue. In other tables they correlated other features like transcription, parallel motor activity and focus of attention.

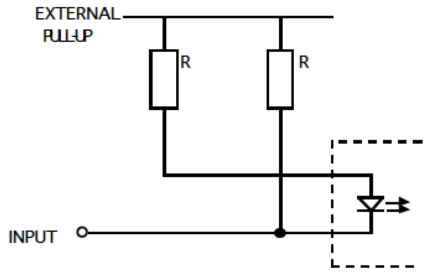
Time	PD	Mi	Ma	Dialogue	Actions
21:30	R1F	Ju	Bu	We need a low impedance OK	
21:32	1S	Ps	Bu	the easiest way to configure it is to do something like this I guess	
21:42				We provide an external pull-up	
21:51				And some pull-up voltage	*Adds the following to the left of the previous drawing.* 
21:56	1F	Ju	Bu	which gives us, the ability for the user to determine that voltage	
22:04	1S	Ps	Bu	A resistor of some sort which is fixed by the external pull-up and this becomes our input from the outside world and what happens now is that when ... its an	
22:18	1B	An	Bu	active low input isn't it because under normal circumstances the LED would be off if there's nothing connected to there the LED would be off ... when we pull that down to ground that will be the way that the input is made the LED will glow, seems reasonable ...	

Table 1. Suggested segmentation in the second design episode.

Fig. 3.4 Gero and Mcneill (1998), described a methodology to investigate the process of designing, in this particular table they show: Time, Problem Domain (PD), Micro and Macro strategies, Dialogue and Actions containing researcher's notes and designer's sketches, sketches and dialogue are not proportional to time scale nor identified by author.

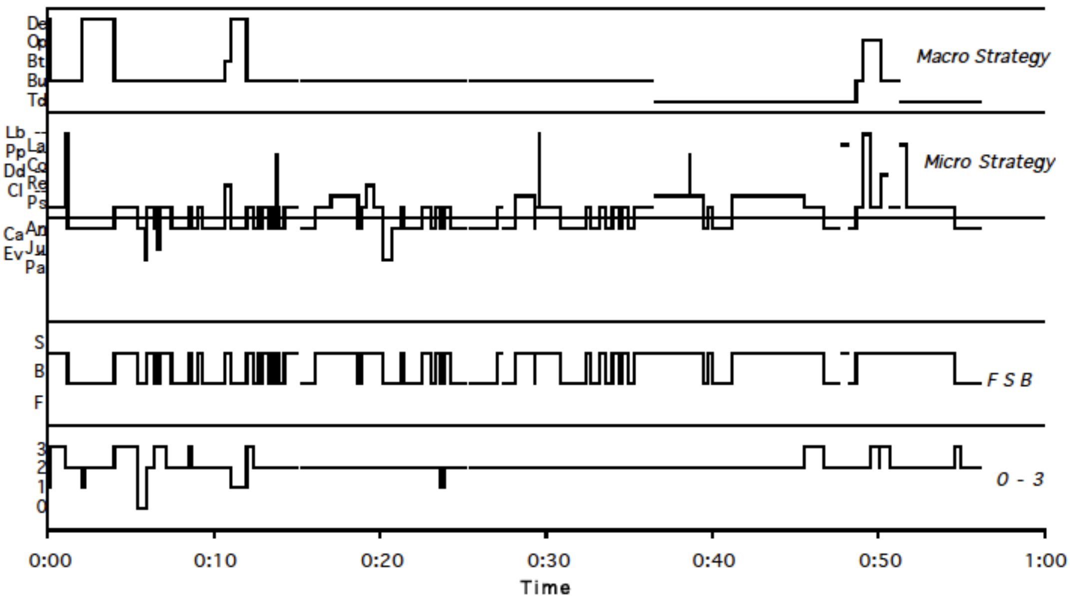


Fig. 2. Activity chart for the first design episode.

Fig. 3.5 Activity chart identifying several features from their coding method along time (one hour total) by Gero and Mcneill (1998), interesting correlations can be detected with this visualisation, sketches were not included nor dialogue.

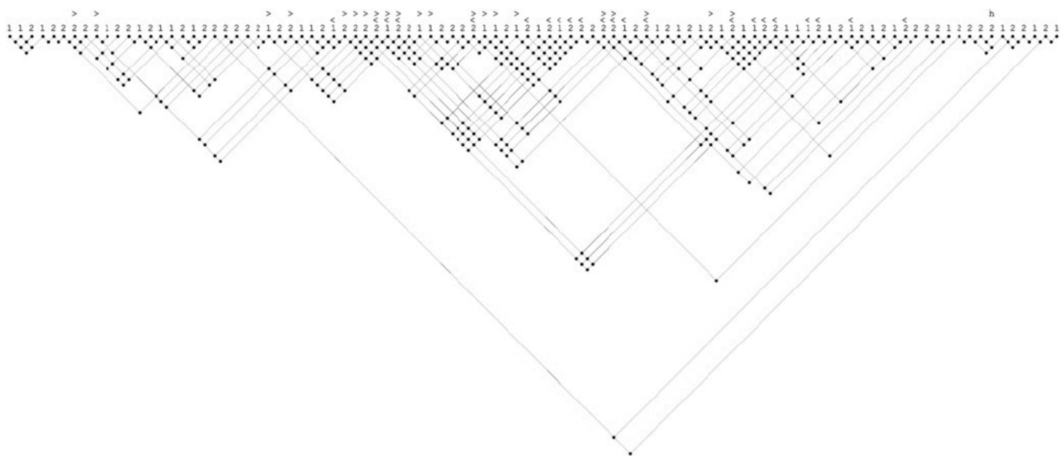


Fig. 3.6 Kan and Gero (2008) proposed new methods to acquire information from linkographs based in clusters and Shannon's entropy. This graphic shows a ten-minute period of a think aloud test, there is no visual correlation with sketches or dialogue.

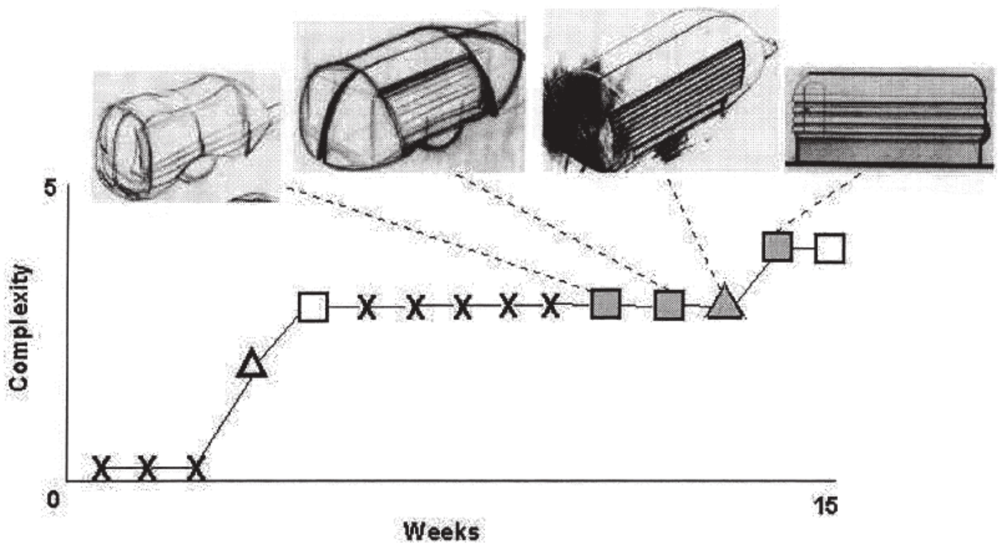


Fig. 3.7 Rodgers et al. (2000) sketch complexity flow in a 15-week long test.

Cash et al. (2013) following network theory of hubs and connections, proposed a method for using visual information analysis, in order to identify and analyse complex patterns in designers' activity. They studied exclusively designers' computer usage, which was recorded with specialised software. Figure 3.8 shows the 100 min of internet-based information search that participants performed.

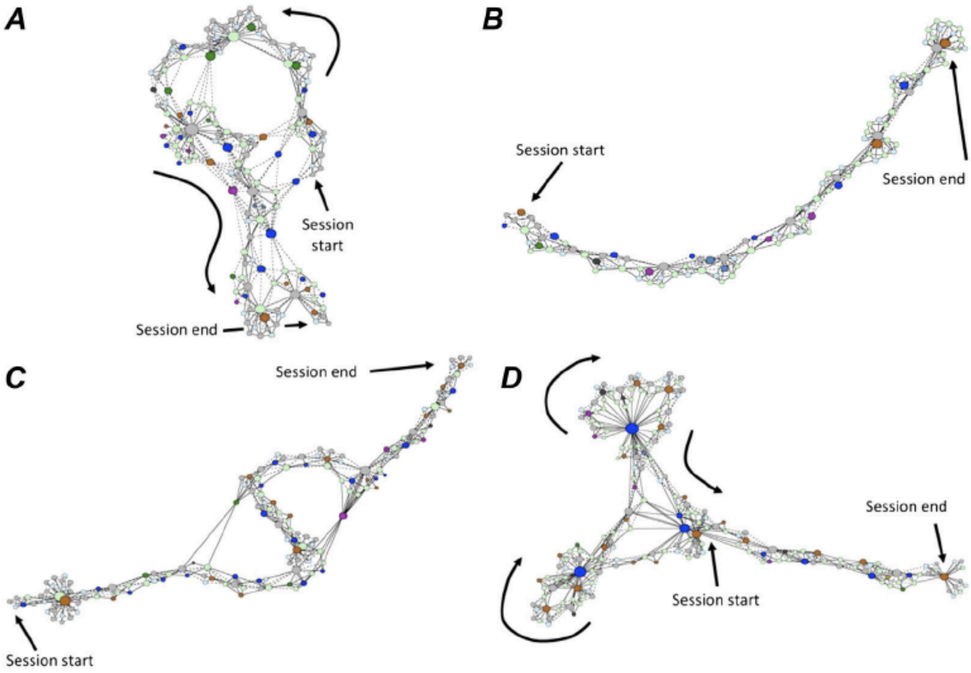


Figure 5 Four typical patterns of activity: overall iterative A, local iteration only B, mixed C and a distinct separation between local iteration and overall iterative working phases D

Fig. 3.8 Different patterns of designers' activity during information search on the internet identified by Cash et al. (2013).

The previous examples are just some of the many that can be found in literature, after this brief analysis distinctive categories could be proposed, the visualisations that are time-based, others are event-based, correlation-based or flow-based. Each one has been designed to highlight a certain feature, which unavoidably makes them loose other aspects that for the particular research were not relevant. In the case of this research the main purpose is to visualise all of them in order to identify not only the effects of the tool but also the specific data source where it took place, and also doing so in a way that potential correlations can be found.

3.6. - SELECTED METHODS

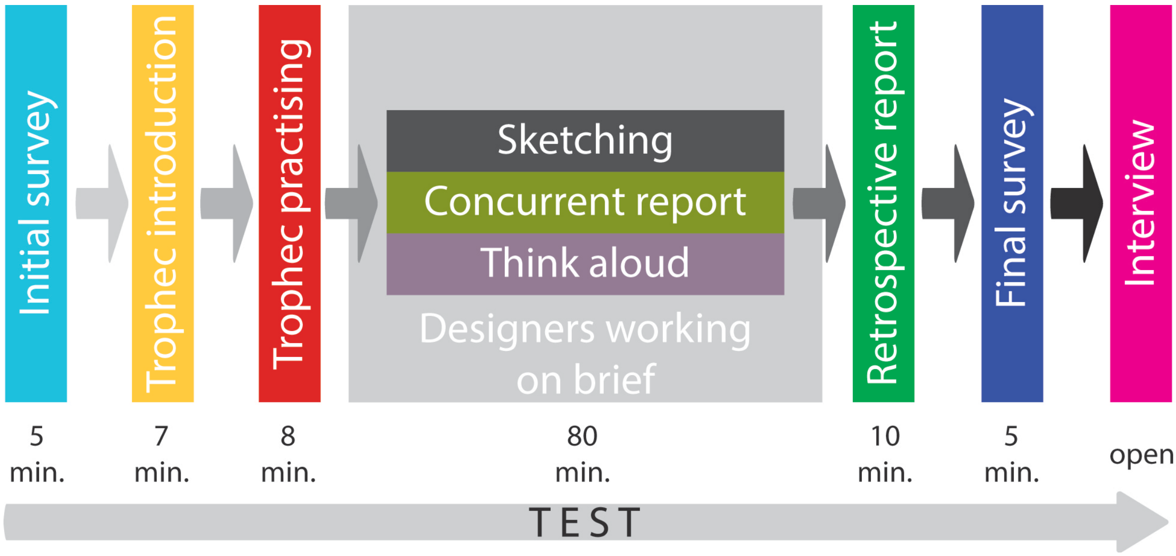


Fig. 3.9 Diagram of methods used, showing activities prior to the test, activities that ran parallel in the test and activities after the test, a more detail explanation can be found in chapter six section 6.2 p.203.

This chapter, partially a complement to the literature review, has shown some of the principal methods to capture, analyse and expose the designers' working flow, as well as the methods' particularities and limitations. An important distinction becomes necessary in order to follow an analysis of which methods this research has used.

In the literature several examples were found of researchers testing mainly well-established eco-design tools, with the goal of understanding if designers used the tool, and if so, in which phases of the design process it was most relevant, representing a clear aid for them. In some cases it also considered which sustainable design strategies the tool allowed or promoted designers to adopt, and if incremental or systemic approaches were undertaken. Many of these researchers identified the relevance in early stages of design, and provided useful recommendations for new tools addressing this challenge.

Therefore, this research is built on two fundaments. Firstly, on the importance of incorporating sustainability-related information at the early stages of the design process, and secondly, on other researchers findings when analysing existing eco-design tools. The investigative methods of this research should therefore allow the identification of how the working processes may be influenced or altered, by presenting sustainability-related information in the novel and untested proposed way of 'soft modelling' in early stages (Martinez, English et al. 2012). In order to provide training support for the participants in the use of the tool, three different videos were produced, all of them accessible online and provided in English and Spanish (Martinez 2012). The level of uncertainty regarding how and when this influence or alteration may take form and place, drives this research to adopt a strategy of mixed methods, leading by the protocol analysis through the think aloud method as central structure. The approach for producing the design process visualisations shifts in this research from communicating, to also include the analysis and identification of phenomena.

Recalling Crouch and Pearce's (2012) theoretical lens, this research takes an interpretative approach, where it is only possible to represent some aspects of reality, and by engaging with people, explore habits and interpret practices, with the goal of building an understanding of how the designers relate to practices, objects and systems.

The investigative part of this research was developed in five sequential tests, each one providing insights and experience to the researcher, and thereby informing necessary changes or adjustments to the protocol. This will be reviewed in detail in chapter six. The protocol consisted of a think aloud session of 1.5 hours (which was reduced by some of the professional designers at their own decision or due to unexpected work-related issues) and complemented with concurrent and retrospective reports. The methods selected for data collection are described next.

INITIAL AND FINAL SURVEY

This survey was applied at the start and at the end of the test. It was divided into two sections: the first asking the participant to select from a series of factors related to the life cycle of a product, which of them he or she would normally consider when designing a new product. These factors were selected from the guidelines proposed by Fuad-Luke (2009) after a review of similar ones proposed by other researchers (Burkhardt and Franksen 1980, Brezet and van Hemel 1997, Datschefski 2001, Bhamra and Lofthouse 2007, Thorpe 2007, Vezzoli and Manzini 2008, Yeang 2008). Fuad-Luke's guidelines were used because of their correspondence with the different sources of information that the developed tool produces, and its less technical language but at the same time more punctual and applicable character that was thought necessary for non-experts in sustainability.

The second section asked the participant to assign how much time he or she would allocate to each design process phase. For this reason the model of seven phases process proposed by Aspelund (2010) was selected. It also reflected the non-complex vocabulary used, and the direct, and specific definitions to which students and professional designers could easily relate. The only difference between the initial and final survey was that in the initial one, participants were also asked to provide: gender, years of professional experience, if the participant was interested in applying sustainability criteria in their professional practice, how easy he or she finds applying it, and the main reasons for it.

Originally this survey was meant to detect any possible changes in the participant's perception caused by the presence of the soft modelling tool, in terms of each of the mentioned points. This showed not to be reliable as designers' responses were highly random and no patterns or structure could be identified, this will be discussed in chapters six and seven. Nevertheless it provided interesting qualitative information related to the participants' difficulties in applying sustainability criteria in their professional practice. Other insights were also drawn from the survey, which will be discussed in chapter seven.

SKETCHES

Participants were provided with eight A4-size working sheets, each sheet was numbered in sequential order, participants were asked to use the sheets in that order, but no restrictions were imposed for moving back and forward, in order to allow a natural and probably non-linear process. The possibility of using more than eight working sheets was also open and a final 'presentation' drawing was requested, for which an A3 sheet was provided.

In the case of sets, each member was provided with a different colour pen and asked not to exchange it. This showed to be very useful in complementing information about the social interactions and behaviours during the test; this will be explained in detail in chapters six and seven. No complaints were made about the limitation to using just one pen, thus it is believed that was not detrimental in the intention to recreate the most natural working conditions possible.

The range of working sheets used was very wide, from 3 up to 13. It proved to be generally easy to follow the sequence of the sketches, except in some cases when designers redrew previous sketches several times and in different working sheets. However it was not problematic to determine precisely the sequence and to visually represent it, as reported in detail in chapter six.

CONCURRENT REPORT

Inspired by the method found in Sternberg (2003), the A4-size working sheets included a concurrent survey on each one of them. This was meant to capture the participant's perception about how close or far they felt to achieving a final proposal. Each time they started using a new working sheet, they were required to mark with a cross a pre-printed box with a scale of five (see appendix E p.318). The majority of the participants completed this requirement, in lesser number of cases it was forgotten at the time a new working sheet was used, and was completed later. It was clear that they looked at the contents of the sketches, and recalled memories in order to determine how they felt at that time - no doubt as a posterior reflection. Just two of the 22 concurrent reports were not completed at all.

RETROSPECTIVE REPORT

Immediately after the task was finished, the participants were requested to write on the back of each working sheet (which was requested not to use for sketching), any extra comments or thoughts they wanted in relation to the contents of each working sheet. This activity had the purpose of capturing missing bits of the process, as well as initial reflections on their own work. In the case of sets, comments were also written in the assigned colour pen, so enabling the triangulation of data (like sketches) and the drawing of interesting conclusions about the social behaviour of working in teams. Furthermore it allowed the researcher to identify a list of key words that could guide to the identification of the different design steps on which designers were working. This particular aspect will be shown in detail in Chapter Seven, Section 7.2.8 p.242. Some professional designers could not perform this part of the test due to time pressure.

THINK ALOUD AND RESEARCHER OBSERVATIONS

In all the tests, at least one set of participants was video recorded in order to have the raw data necessary to make the protocol analysis. The methodologies used will be explained further in sections 5.2 p.152, to 5.9 p.200 of chapter five; but in the case of some participant sets, no video recordings were made. Instead, a researcher acting as an external observer registered the events in a log, particularly following the method created by McGown et al. (1998) for sketch identification. Both videos and logs were essential to this research. They allowed the creation of a highly precise sequence of the sketches, the dialogues and other events taking place during the test, which complemented the information in a very efficient way.

The protocols were fully transcribed using ELAN software, which produced very long transcriptions of up to 20,000 words. ELAN permits the specification of the start and finish of a sentence with great accuracy, figure 4.14.

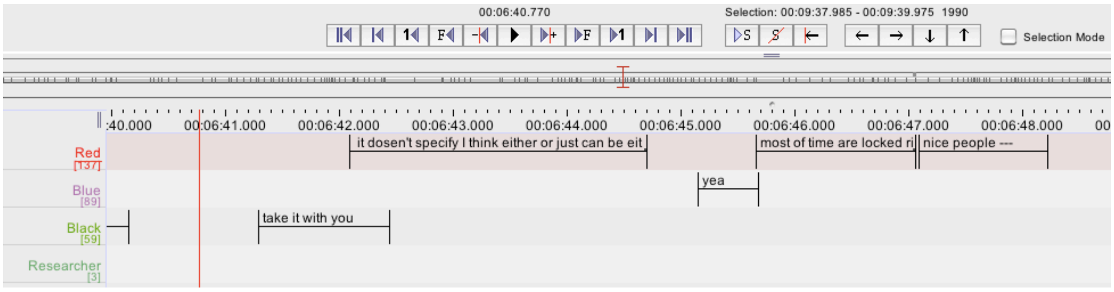


Fig. 3.10 ELAN working screen, particular of verbalisations transcription

The verbalisations were segmented according to the time between one sentence and the next one, with a minimum of 0.2 seconds being set as the time to separate them.

INTERVIEW

In the last two of the five tests performed, the protocol finished with an unstructured interview, which was also captured on video and later transcribed. In it the researcher further investigated issues related to some particular events detected during the test. It provided valuable information, which is discussed in chapter seven and eight.

This main approach attempted to recreate the most natural characteristics of working conditions possible. In 16 tests designers worked in sets of three participants (students), and in 6 individually (professionals). All were given a task and then allowed a limited time (1.5 hours) to propose solutions. The way designers structured the process and organised the entire workflow was free in the first test and structured in the rest. This will be further developed in this section. Working in sets allowed engagement in the previously mentioned dialogue, which intrinsically produces verbalisations of the design process, or in the case of single participants, asking them to 'think out loud'.

In all tests consideration was also given to exploring control and experimental groups, this in order to detect any possible difference related to the presence of sustainable design information provided by the tool, or by designers' own interest and initiative. Also, the possibility of a strategy that permitted certain level of generalisation on the results was explored, which, as discussed previously, is one of the weaknesses of the protocol analysis. A detailed description of all tests is provided in chapter six. However, the general settings of each test are summarised below, with the objective of highlighting for the reader the insights gained from each test that led to certain differences in their structure.

Design task

The relevance of the design brief for the development of the entire problem and solution space has been previously discussed in chapter two section 2.7 p.86. The researcher firstly analysed the possibility of producing a brief with an open-ended task, which allowed the designer the opportunity of moving beyond the physical object, and of experimenting with services and systems. This followed Brezet and van Hemel's (1997), and Vezzoli and Manzini's (2008) four types of incremental up to systemic changes. Nevertheless, in order to avoid any bias, it was decided to search for an independently made brief, and one that provided the possibility for designers to arrive at incremental or systemic changes. After researching some of the main national and international institutions promoting design contest or projects, and providing a design brief, it was finally decided to use NESTA's "Hands off my bike" design challenge, this is covered with higher detail in chapter five section 5.3 p.153.

Pilot test

The objective of this first test was solely to inform and refine the main investigation protocol; it was not intended to contribute final data.

Four design PhD students, divided in two sets of two participants, performed this test. Only to one set was shown the instructional video of the soft modelling tool and was allowed to use the tool freely at their will. Acknowledging the relevance of computer access for information search, as exposed by Cash et al. (2013), both sets had the option of free use of the computer, which was always at hand and turned on. The researcher video recorded one group and attempted to follow both groups by making notes in a log; in figure 3.11 the video recorder set in the pilot test can be seen at work.

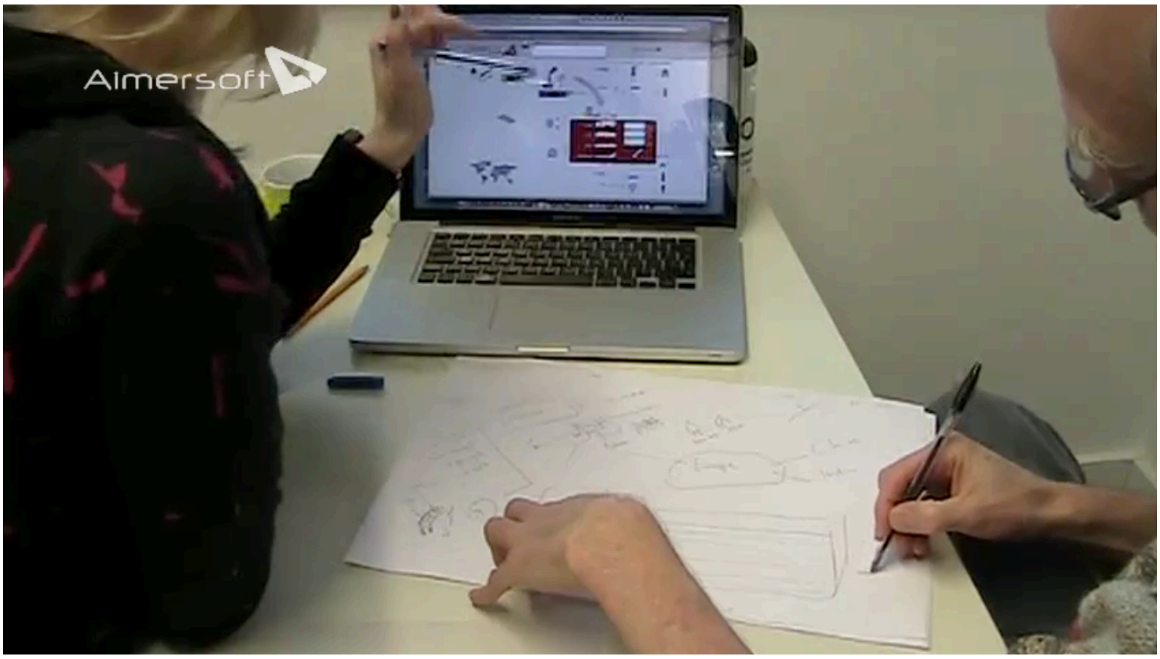


Fig. 3.11 Pilot test video recorded set at work

This final task showed to be too complex, as the working flow was too fast to allow the capture of all the details in a log. It was therefore concluded that each set had to be followed by one researcher.

NORTHUMBRIA TEST

This test took place on January 2013. Thirty-nine students from the Design for Industry undergraduate program were divided into three groups, two controls and one experimental. Each group had several sets of three participants, in each group one set was video recorded, and one researcher followed each one of the rest, with nine experienced researchers participating in this test.

One control group was simply given the task to solve, with no particular instructions. The second control group had a 'raw data' sheet with the internet addresses of the information sources the soft modelling tool uses in its calculations (the 'raw data' sheet used can be consulted in the appendix F p.319). The tool was presented only to the experimental group and 10 minutes of familiarisation allowed before starting the test, there were no instructions regarding when to use the tool, it was free at their choice.

The objective of the general settings of this test was to provide a larger number of samples in order to attempt a generalisation of findings by establishing a connection between the high detail information of a think aloud, and the triangulation of the complementary methods mentioned above. Unfortunately, the noise level captured in the video recordings made it impossible to transcribe the participants' dialogues, this happened because all sets within a group worked together in the same room, and some video cameras were placed too far away from the participants, therefore it was learned that sets must be separated in different rooms and the camera should be placed more carefully considering the light and sound source.

Nevertheless, the researchers' logs provided valuable information, and the general outcomes of this test informed about important changes in the protocol for the next tests. These are discussed further in chapters six, seven and eight, but are summarised here as follows: no significant difference was found in the control and experimental groups, suggesting that the incorporation of sustainability criteria may depend more on personal awareness, skills, and interest; the simple presence of the software and sustainability information seemed not to be enough; it also suggests that in early design stages it may not be appropriate if the natural iterations of the design process are not considered, and especially allowing reflection periods.

These considerations led to the key proposal of incorporating into the protocol such reflective moments in the form of design process steps, which would allow two important issues: one, to permit moments of reflection with the use of Trophec between steps, and two, make these steps relative to the early and late stages of the design process. Therefore, ideally not only capturing the influence of the tool, but if any difference between them.

MEXICO TEST

On April 2013 a new test was prepared, this time in collaboration with the researcher's former working institution, the Tecnologico de Monterrey in Queretaro City, Mexico. Twelve Industrial Design students from the undergraduate program participated forming four sets of three participants, using the exact same protocol as that used by the previous test's experimental group. One important difference was that the total test time was divided into three design steps: concept generation, refinement and definition.

Other difference was the use of the think aloud method exclusively, the experience of capturing the designer's working process with researchers observing and writing in a log was found rich, the sketches sequence was followed very precisely, but in order to move into a more accurate and unbiased analysis was not considered appropriate. Each step was 30-mintues long, and between steps 1 and 2, and steps 2 and 3, each set was asked to use the tool, and allowed each time 10 minutes for doing so. The author could not be present in the test, and all the testers were trained with email communications and video-conferencing. Unfortunately, once the data arrived and was reviewed in detail, important failures in the protocol were found, leading to the total discard of the test. Nevertheless, some evidence of the changes in the protocol indicated that small reflection periods during conceptualisation could be the appropriate way to proceed with the research.

ROYAL COLLEGE OF ART

After engaging with professional designers one and two (June 2013), one more test was performed, this time in collaboration with the Royal College of Art in London in early October 2013, in which nine students from the Vehicle Design masters program were organised in three sets of three. The first set (RCA1) reproduced the experimental group of the Northumbria's test: with no design process steps and no precise instructions on when to use the tool; the second and third set had the same protocol previously given to the professional designers, which was used in the discarded Mexico test. Only in the case of set three was it specifically requested to describe how the final product would end its useful life. This test had two main objectives: one, the first set was intended to repeat and corroborate the findings of the experimental group of Northumbria test, which was fully achieved; two, sets two and three were to compare experienced and novice designers, as well as individual and team work, and complement the general conclusions of this research.

PROFESSIONAL DESIGNERS

It is often mentioned in literature the lack of examples of tests performed by professionals, which is largely explained by the fast pace in professional practice, and the difficulty of finding time to invest in this type of research. The researcher was able to engage with six professional designers in mid October 2013, all of them with 15 or more years of experience. The protocol was the same that the one prepared for Mexico's test and used for sets two and three at the Royal College of Art. The only difference was that they worked individually. Therefore, a 'classic' think aloud method was applied, all sessions were captured on video and excellent quality in both image and audio was achieved. With one exception, all participants were tested in their working environment. These tests represented the main source of evidence for this research.

PARTICIPANTS SELECTION

In all tests an attempt was made to engage with participants as closely related to product or industrial design as possible as main criteria of selection. A strong effort was made to include both students and professional designers in order to obtain also the performance of experienced and novice designers. To achieve it the researcher's contact network was used. For the pilot test, the researcher asked for the participation of his fellow PhD students at Northumbria's Design Department; test two was facilitated by the Design for Industry staff from the same institution, which allowed one class day to be used for this research. As mentioned before, test three resulted from a direct request made to the researcher's previous working place. The researcher's second supervisor, who works in that institution, facilitated the collaboration with the Royal College of Art.

In the case of professional designers, the researcher first identified 45 design consultancies in the United Kingdom through the online directories mentioned by Self (2011). All were contacted by email, only three replied but none of them accepted the invitation to participate, citing a lack of available time. Therefore, the researcher returned again to his contact network, this time successfully obtaining the consent of nine designers, just like the students, participants were selected for their affinity to product or industrial design and with the longest professional experience available. Ultimately, due to unpredictable situations like diseases or working compromises, only six participated, two of them in Italy (in July 2013) and four in Mexico (October 2013) – one had 12 years of professional experience, three of them had 15 years and the other two 23 years.

ETHICS AND DATA HANDLING

The first activity in all five tests was to present the researcher and the test. All participants were advised of their right to withdraw without penalisations or obligations at any moment during the test. Afterwards, participants were required to sign a consent form, one general to all participants, and a second particularly granting permission to be video and audio recorded (for those participants who were in the test where video or audio recording was deemed essential). Once the test finished a debriefing took place. A guide of the protocols was printed and read during the test and these can be consulted in the appendix A p.306 and B p.310.

There were two main types of data: paper based (sketches, surveys and self-reports), and video with audio. For all participants a naming code was used in order to make the entire process anonymous. With the exception of the consent form, which provided the option of participants giving their email to be kept informed on the research progress, no personal contact or identification information, such as name, address, ethnic group, etc was ever requested, and all paper and digital files contain exclusively the coding names.

The coding used followed the structure shown next:

Pilot test (not intended to contribute to final data)

- C: Control set
- T: Trophec set

Northumbria's test

- CA: Control A, set 1 to 4, according to pen colour: blue, red or black participant.
- CB: Control B, set 1 to 4, according to pen colour: blue, red or black participant.
- TA: Test A, set 1 to 5, according to pen colour: blue, red or black participant.

Mexico's test (discarded)

- D1, according to pen colour: blue, red or black participant.
- D2, according to pen colour: blue, red or black participant.
- D3, according to pen colour: blue, red or black participant.
- D4, according to pen colour: blue, red or black participant.

Royal College of Art test

- RCA1, according to pen colour: blue, red or black participant.
- RCA2, according to pen colour: blue, red or black participant.
- RCA3, according to pen colour: blue, red or black participant.

Professional designers

- PRO1
- PRO2
- PRO3
- PRO4
- PRO5
- PRO6

All paper-based data has been stored in a key-locked cabinet inside Northumbria's Design Department. Digital files have been stored in the researcher's personal computer and a backup copy in an external driver stored in the same key-locked cabinet.

The appropriate clearance from the Faculty's Ethics Committee has been granted to this research, which can be found in appendix M p.705.

DATA VISUALISATION

Due to the uncertainty of exactly how the tool may affect the working process, a chart was developed that allowed the visualisation of the selected methods. The first charts were developed for Northumbria's test, and contained:

- The retrospective self-report
- The researcher's comments allocated accordingly to the period that the working sheet had been used
- The length each particular working sheet was used, with an image of each working sheet and each single sketch accordingly to their creation sequence
- Goel's (1995) lateral and vertical transformations
- Sketch 'complexity level' (McGown, Green et al. 1998)
- The concurrent report
- The final 'presentation' sheet
- Brief judging criteria score
- Word cloud from participants' retrospective report
- Score related to Fuad-Luke's (2009) sustainability criteria
- Graphics showing the initial and exit surveys differences

All it was presented in a horizontal 1-meter long poster, figure 3.12.

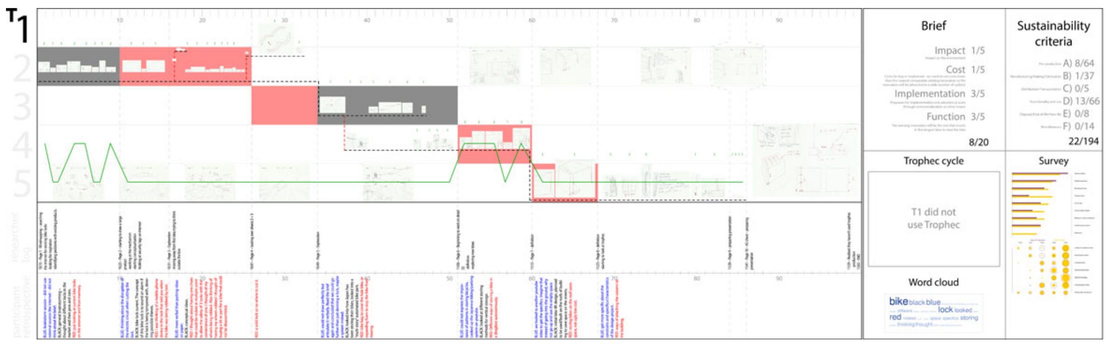


Fig. 3.12 Sample of chart developed for Northumbria's test

Important lessons were learnt from this first visualisation attempt: firstly, allocating retrospective report and researcher's comments by working sheet did not present any visual relevance in order to complement the rest of the information; secondly, placing single sketches images to re-create the flow was not effective, due to the need to change their size in order to fit them in the different spaces, thereby losing the proportion between them. Some were so small that they were impossible to see; lastly, word clouds and surveys graphics did not provide any relevant information.

Sketch complexity and concurrent report did provide a clear view of the designer's working progress, as did the lateral and vertical transformations. Nevertheless, because of the horizontal setting of the poster, important confusions emerged: these transformations were related to the time flow (horizontally expressed), not to the Cartesian spatial dimensions, therefore vertical transformations were being read as lateral (horizontal) and vice versa.

With these experiences, and in later tests with the transcriptions from the think aloud protocol and video recording of the designers' sketching and computer usage, a higher detail of information was available. New charts were developed for RCA's sets and professional designers. In them the full think aloud protocol was captured, but this time it was allocated accordingly to the moment and duration of each sentence with a precision of seconds, evidencing more abundant dialogue periods or silences. Participant and researcher's dialogue were both included and identified with different colours, figure 3.13.

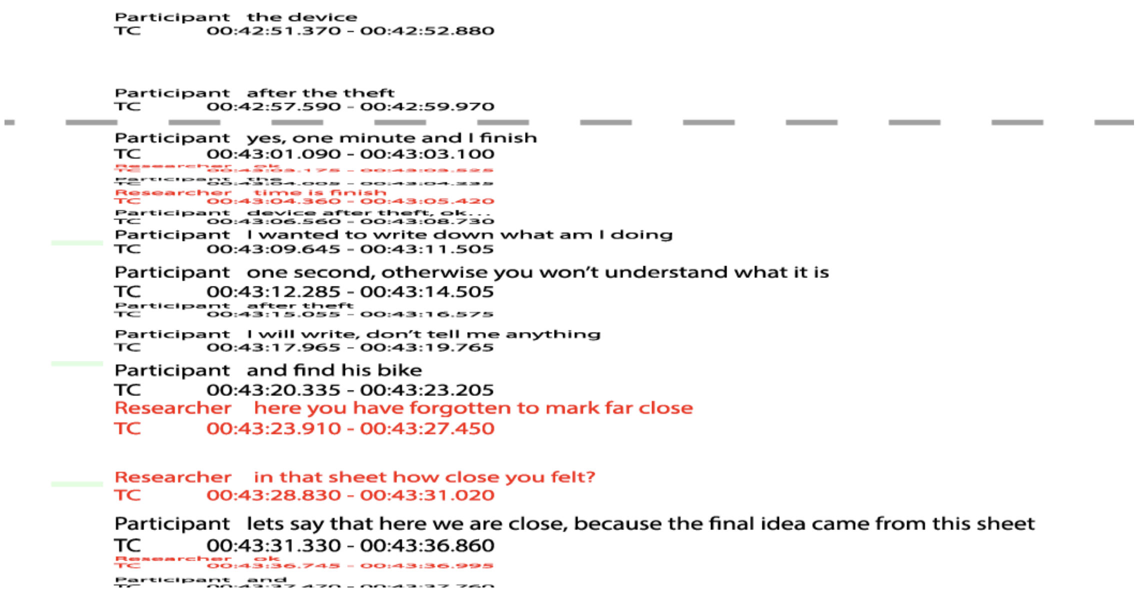


Fig. 3.13 Detail of transcript in flow chart

Sketches were represented by coloured blocks in the time and duration of their creation, and differentiated between just figural (green), and participant's general notes (purple), and notes complementing figural representations (cyan). The sketch process was, as expected, not linear, therefore a series of arcs (red or orange) connect the sketches in their chronological sequence. Lastly, the sketch's complexity and concurrent report were simplified. New features like the protocol structure as it was planned, and as it actually happened were shown by coloured blocks. Furthermore, based on the transcriptions and using the key words identified, plus the descriptions found in Günther et al. (1996), the design process steps in which the participant was working were identified, allowing the visualisation of the non-linearity of the process. Computer usage was also shown in time and duration, and in some cases by the different types of software used.

The setting of the graphic was now made vertical, in order to avoid confusions with lateral and vertical transformations, which now included the moment of new idea generation and the sketch relating to each flow. These charts now present the mixed methods in a purely graphical way (figure 3.14), making it easier to see connections between multiple sources. They were produced in more manageable A3 size. Detail of these charts will be presented in chapter six, sections 6.4 p.219 and 6.6 p.238, and their relevance for data analysis and insight generation will be discussed in the final chapters of this thesis.

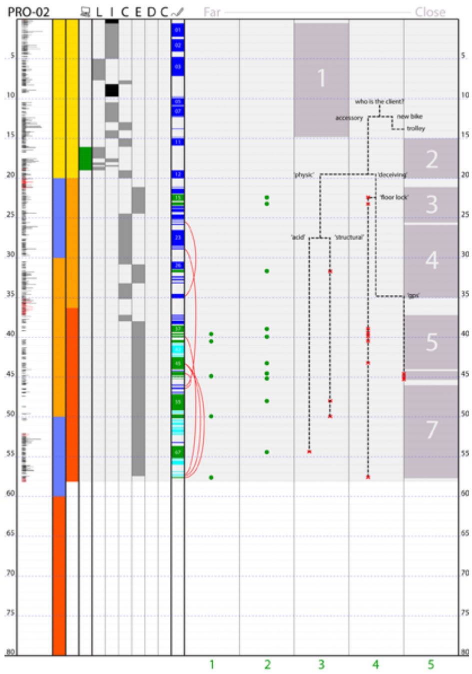


Fig. 3.14 Sample of chart developed for the RCA's and professional designers test (source: the author)

ONLINE DATA

The soft modelling tool will be fully described in chapter five, but for the purposes of this chapter it is important to mention that the tool is internet-based, and in addition to being used by participants in the mentioned tests, the tool has been freely available to anyone wanting to use it since October 2012. The researcher promoted the tool and communicated the research through different channels:

- Exhibition in Design School's foyer during the visit of MP Chi Onwurah Oct 25th 2012.
- Sustainability Innovation Congress, Bonn, Germany Oct 2012 (Martinez, English et al. 2012).
- 10th symposium Mexican Graduate Students Association, Imperial College, UK, 2012

- Conference at Centro de Investigaciones en Diseño Industrial, UNAM, Mexico City, 2012
- Conference at Francisco de Vitoria University in Madrid, Spain, 2012
- Conference at Istituto Europeo di Design, Madrid, Spain, 2013
- Conference at Francisco de Vitoria University in Madrid, Spain, 2013
- Article in the Royal Society for the encouragement of Art, Manufacturers and Commerce's (RSA) program 'The Great Recovery' (Martinez 2013)
- Article in the Environmental Sustainability group of InnovateUK (Martinez 2013)
- Article in Latin American online design forum 'Foro Alfa' (in Spanish) (Martinez 2013)
- PhD design emailing list
- O2 network mailing list
- Social media: a Facebook page for the tool was opened, and also through researcher's twits, Linkedin groups, and personal contacts in Facebook and email

All these efforts resulted in almost 400 registered users, from which, up to Monday 13th January 2014 when the data for analysis was downloaded, 94 active users had produced 200 cycles. Each cycle registers all the users life cycle choices in five main steps: material resources, manufacturing methods, transportation means, usage and recycling.

The tool requests the user to provide a title for the cycle in order for it to be saved. The titles were normally the type of product the user was analysing. Furthermore, each user, when registering, was requested to specify: company or school, position, and country.

In figure 3.15 the audience overview is shown as registered by Google Analytics for the period between October 25th 2012 and January 12th 2014. Figure 3.16 highlights the 69 countries from which the visits originated, and finally figure 3.17 tracks the flow of users when visiting the tool, highlighting the path of how those users reached the cycle creation page.

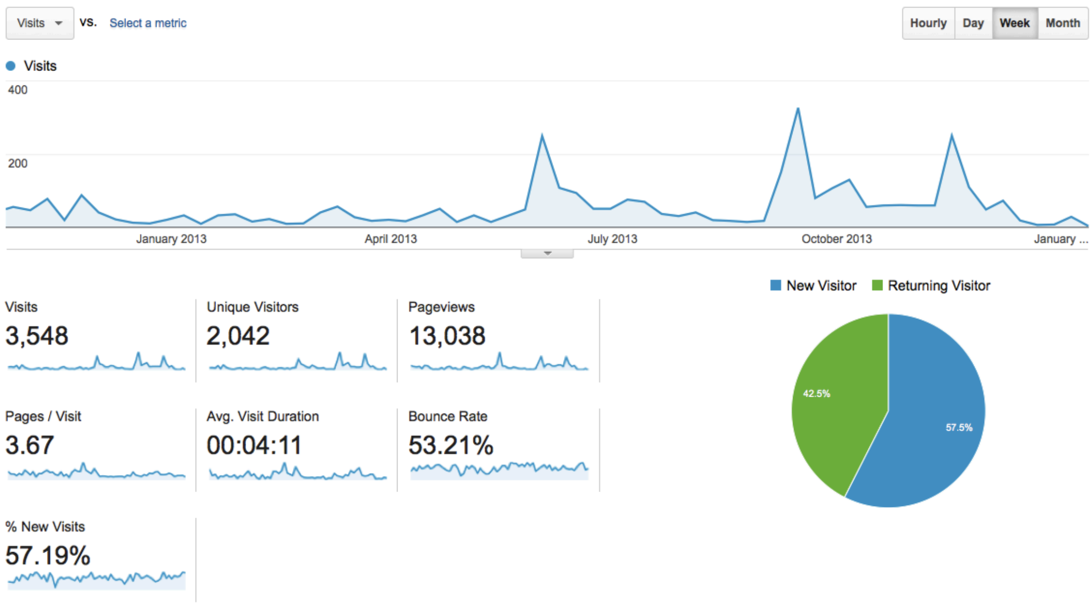


Fig. 3.15 Activity overview (source: Google Analytics)

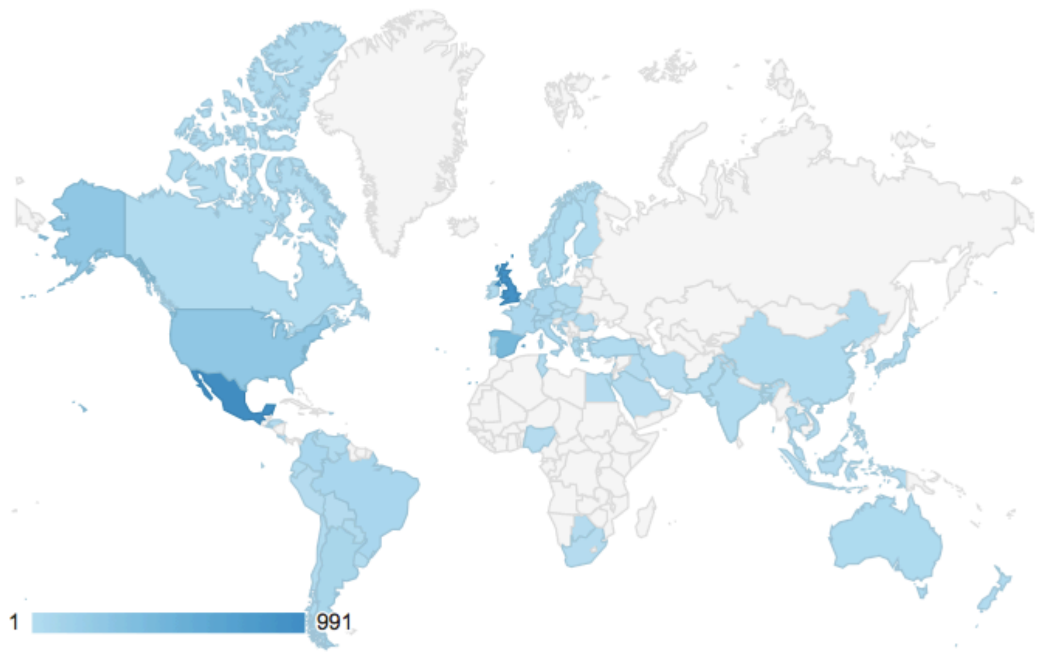


Fig. 3.16 Origins of Visits (source: Google Analytics)

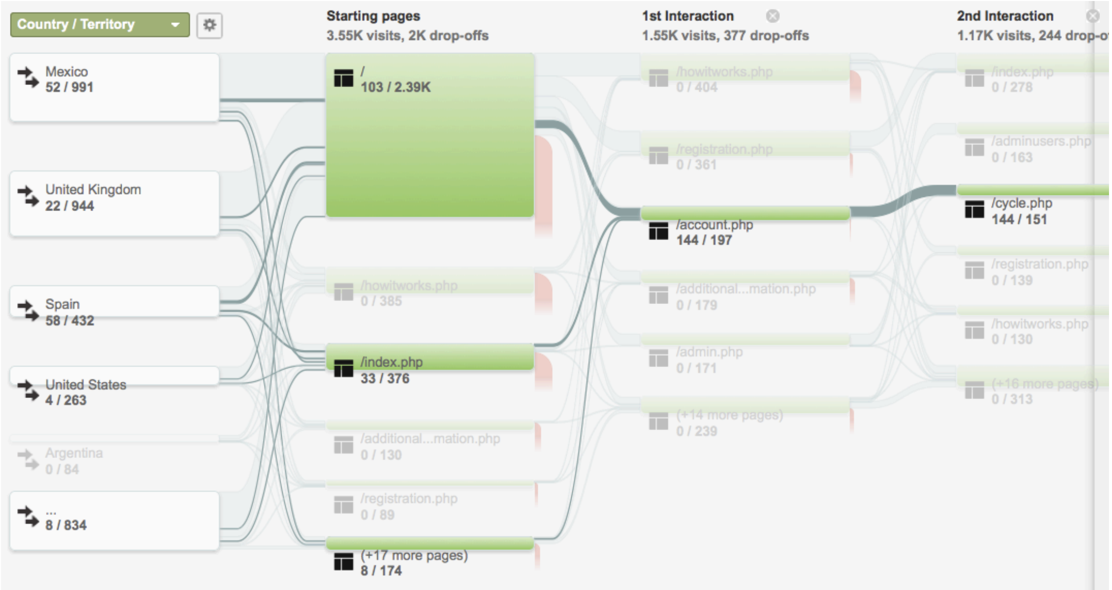


Fig. 3.17 Flow of visits, highlighting the path followed by users reaching the cycle page (source: Google Analytics)

Data gathered with this method is exclusively quantitative, and has been used to aggregate users choices - a detailed analysis of this data is provided later in this document. Nevertheless it is relevant to mention that 37 users (39.36% of total) used the tool more than once, creating a total of 139 cycles (69.5% of total). This is particularly important because it has allowed some insights into designer's usage through time, and in some cases comparisons between different products.

3.9. - CONCLUSIONS

The interest of this research in testing if the delivery of sustainability related information while designers are working in the early stages of a design project, produced the analysis of research methods presented in this chapter. The focus is therefore in the designer's working process, in the need to understand what the designers are thinking and the way they progress in the working flow. Acknowledging the diversity of approaches from one designer to another, added to the uncertainty in how the tool with which delivers the information will affect the different working processes, lead to a mixed methods approach, where external representations in form of verbalisations, figural representations and concurrent and retrospective reports needed to be captured and analysed.

Furthermore, this research found the opportunity of a new way for visualising the different data sources in order to identify these influences and possible correlations between these sources. This visualisation chart became a design project itself where initial failures were detected and corrected, and a final version provided a very efficient way to analyse the designers' working process.

The uncertainties mentioned above produced changes in the way the test were carried out and some of the methods used, a brief description was provided in order to create a context that will make further reading more comprehensible. Nevertheless, the detail of how the investigative process was carried out, feedback itself and evolved will be further discussed in chapters five and six. Yet, there is a positive result on the effectiveness of the selected methods in capturing the designer's working process, but it showed as well that for the purpose of this research, not all of them were necessary. In order to identify how designers integrate the 'subliminal' and the 'marginal' clues (Polanyi 1969) within a product's life cycle, it is essential to capture their verbalisations in a think aloud session, but even more important is to allow pauses and iterations in the working process, where analysis and reflection become central activity.

Chapter 4 – SOFT MODELLING, LIFE CYCLE VISUALISER FOR EARLY STAGES OF NEW PRODUCT DEVELOPMENT

4.1 - INTRODUCTION

Fig. 4.1 Name and logo developed for the tool

In the literature review the relevance of integrating sustainability considerations at the early stages of new product development was found (section 2.5 p.46), it was equally revealed that there is a lack of appropriate tools for the working culture of designers at that relevant step of the design process. The eco-design tools most commonly mentioned in literature were also presented (section 2.6 p.53) and relevant researchers' arguments about why designers don't use these tools (section 2.5 p.47 to 53). The reasons are multiple, one kind is external to designers, like the design brief been written by management and marketing, or inexistent market demand; and the other are internal, as presented by Stevenson (2013) such as personal motivation, capabilities and understanding. Some recommendations for new tools attempting to overcome these issues were compiled from other researchers' work (section 2.9 p.99). This chapter will present the rationale behind the development of the tool tested in this research and its working structure, which is a first attempt to capture these recommendations and face the task, so the reader in the following chapters can have a better understanding of the narration.

SOFT MODELLING AND THE CREATION OF TROPHEC

The literature review for this project was an almost continuous activity, in figure 4.2 it can be seen that the development of the tool started at the eighth month of the research project, the majority of the recommendations and characteristics for eco-design tools for early stages were found later and could not be included in the tool's design. Nevertheless, the idea of engaging with multiple aspects of sustainability and doing so in early stages of product development was clear since the beginning. Furthermore, the amount of variables and the complexity raised by their interconnectivity and interdependence, gave a computational approach as ideal in order to produce an interaction with the user that other type of documents, like cards, charts, word processors or PDF files cannot achieve. “Interactive” here is meant as be designed to respond to the actions, commands of a user (Merrian-Webster 2014). Rogers, Sharp and Preece (2011) define it as ‘creating user experiences that enhance and augment the way people work, communicate and interact’.

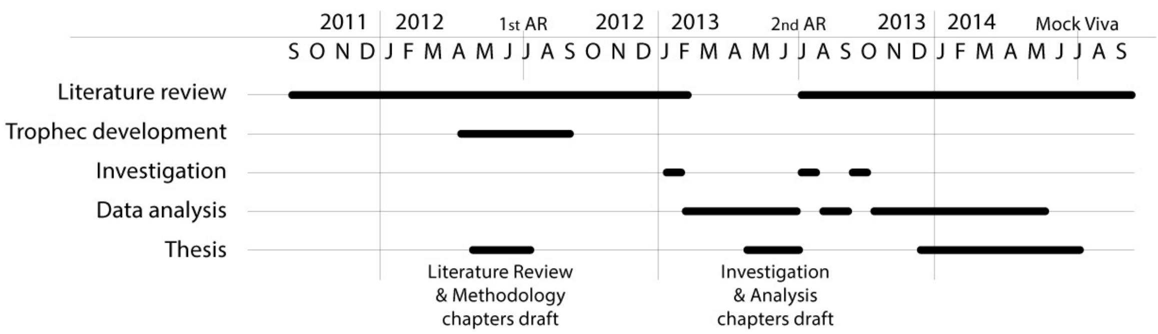


Fig. 4.2 Research time line

Collado and Ostad’s (2010) proposition of ‘soft information’, and similar reflections by Sherwin (2000) and Lindahl (2005), lead to seek a deeper understanding of the term. The Oxford Dictionary (2014) defines ‘model’ as: ‘a simplified description, especially a mathematical one, of a system or process, to assist calculation and predictions’.

The terms ‘hard’ or ‘soft’ are some times added when the model being built considers all factors and possibilities in a deterministic fashion for the former, or a more simplified and holistic approach is taken in order to gain speed and a broader perspective for the latter. This is particularly useful when the researcher faces more qualitative than quantitative information, or when there is no solid ground where to start as is often the case in Social Sciences (Hartmann 1996).

Falk & Miller (1992) note Professor Herman Wold as the developer of a soft mathematical and statistical model for the social sciences, where ‘is soft in the sense that it makes no measurement, distributional, or sample size assumptions’. They explain further: ‘as an aid to researchers, soft modelling provides a system for expressing theoretical ideas about a sequence of events. It can be thought of as a tool for assessing ideas by relating theoretical interest to observations of the world as experienced’.

Therefore, the approach was to use a ‘soft modelling’ system with the goal of creating ‘the optimal linear predictive relationships among variables’, not a final statement of causality (Falk and Miller 1992). In other words and focusing on this research, it seeks to highlight the connections and interdependencies among the life cycle steps of any given product in order for the designer to make more informed decisions; this is, switching designer's perspective from the particulars to their theoretical coherence (Polanyi 1969).

On top of the recommendations for new eco-design tools found in literature (section 2.9 p.99) and the understanding of 'soft modelling' conjugated with the review of commonly used eco-design tools (section 2.6 p.53), produces a series of basic characteristics that can be described as: the tool must avoid large amount of information specially in text form, the life cycle should be presented entirely through graphic means like icons and should be visible constantly. Therefore, variables input and deeper information about them should be presented in popup windows, thus maintaining the minimum possible number of elements in the initial screen. Colour code the life cycle steps so any information related to each can be easily distinguished. Clear understanding of the tool usage flow: give clear information about where the user is, what is next and what the options for the next step are. Avoid the use of expensive data sets; therefore, use public open source data. The impact calculation should be initially presented in an abstract way, through means of points or other elements that the user can make reference and understanding easily. Open access through the Internet and the possibility to be used in mobile devices.

Lastly, the name 'Trophec' is the contraction of 'Trophic Economics', which the author devised inspired by the 'Trophic Levels'. The word 'Trophic' has its origins in the Greek word τροφή (trophē), which means 'feeding' or 'nurturing'.

In biology it is used to describe the level that an organism occupies in a food chain or 'Trophic Level', which are divided into three main levels: Producers (autotrophs): they use nutrients from the soil or ocean and produce their own food through photosynthesis. Consumers (heterotrophs): herbivores (eat only plants), carnivores (eat other animals) and omnivores (eat both animals and plants). Decomposers (detritivores): fundamental organisms that break down dead plant, dead animals and waste, they release back into the ecosystem nutrients (original compounds) to be used again by plants.

In order to use Trophic Levels to understand an ecosystem structure, and how they manage to sustain themselves, an important distinction must be made between the number of organisms, their biomass, reproduction rate and the energy they use and they have available for the next Trophic Level. In figure 4.3 the 'Trophic Pyramids' are shown. They are a helpful way to visualise the sustainability of the system (or the stability of a given community).

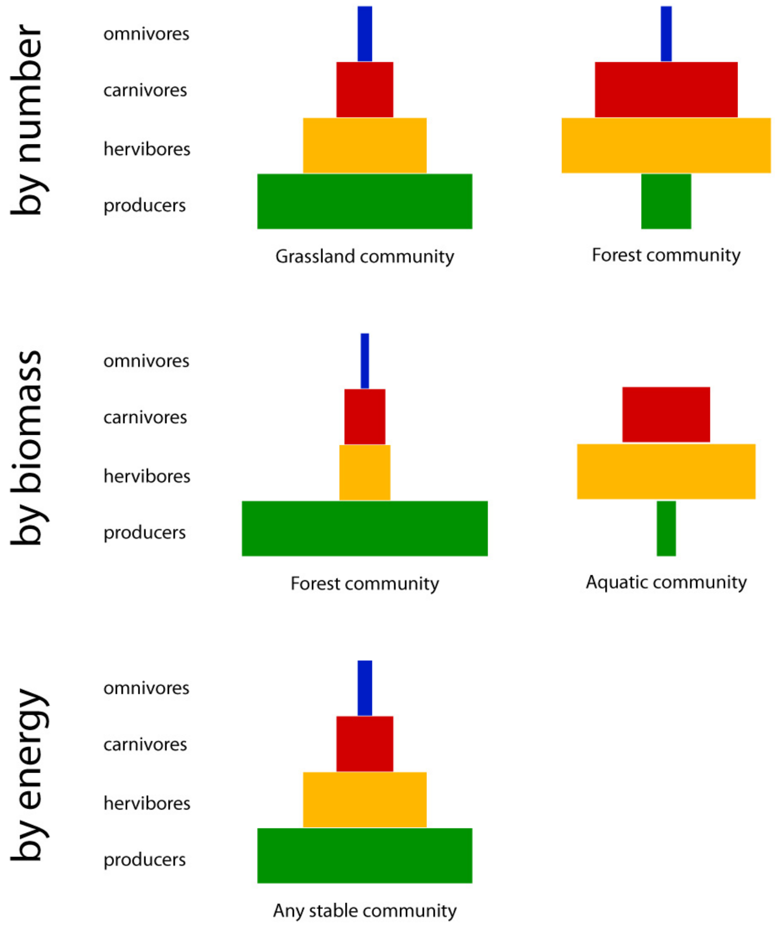


Fig. 4.3 Trophic Pyramids, left column: sustainable systems, right column: not sustainable systems, after: (Mader 2010)

Accounting Trophic Levels by their population number, some ecosystems would show a greater quantity of consumers than producers, which could be translated into a non-sustainable community. If the same is accounted by biomass the same can happen: a forest community has a low number of producers, but their biomass is by large greater than the one of the consumers; nevertheless it is not the case of an aquatic community in which producer's biomass is very low (phytoplankton) but their reproduction rate is quite high.

Therefore, the most accurate method to determine the stability in any given community is through the accounting of the energy available for the next level. Producers make great quantities of energy, from which some is used by them (growth and metabolism), some is available for the next Trophic Level (exergy), while some is simply lost (entropy). In this way gross primary productivity and net primary productivity of any Trophic Level can be distinguished.

There is an interesting link between Trophic Levels and economics, and it was first made in fisheries, the earliest scientific reference found is attributed to Ney (1990).

In his study Ney (1990) describes relevant points for fisheries to be managed in a sustainable way, from a biological point of view two main issues can be identified to achieve balance:

- Determination of source supply: which food type will be used, if the 'prey' selected is appropriate for the 'predator' in terms of the biomass available and energy embedded capable to be transferred into the 'predator'. In terms of biomass, not only is the total amount to be studied, but also the reproduction rate and maturity growth of prey.

- Assessment of viability: Ney (1990) defines 3 conditions for 'successful feeding' that must be sequentially met:

1.- Distributional availability: predator and prey must coincide in the same place at the same time.

2.- Behavioural availability: prey must be recognised as a potential meal and be catchable by predator.

3.- Morphological availability: prey must be physically ingestible by its captor.

The magnitude of influence of these three conditions varies with predator, prey and the system containing them. Therefore, prey distribution patterns, reproduction regulation and predator consumption manifested in growth, metabolism and waste are key factors for successful feeding (Ney 1990).

If in the last paragraphs the word 'prey' is substituted for 'resource', and 'predator' for 'consumer', an interesting series of principles for a sustainable development of human's goods production and economy could be drawn as inspiration.

Therefore, trophic levels could be seen as a base ground for new business models in which matter and energy are pivotal, and closely related to the context in which the product should be manufactured and used. This through the scale and size concept proposed by Daly (Daly and Farley 2004, GundInstitute 2011), and its distribution: clumped (centralised), uniform (decentralised), or random (distributed) (Mader 2010). It was after the author's idea of 'Trophic Economics' that the research of Ney (1990) was found as the only previous reference to such term, and which contents provided further structure to the argument. Therefore, the author developed the 'Trophic Business Models' (figure 4.4) as a first approach to visualise it and offer it for practical application and were also included in Trophec.

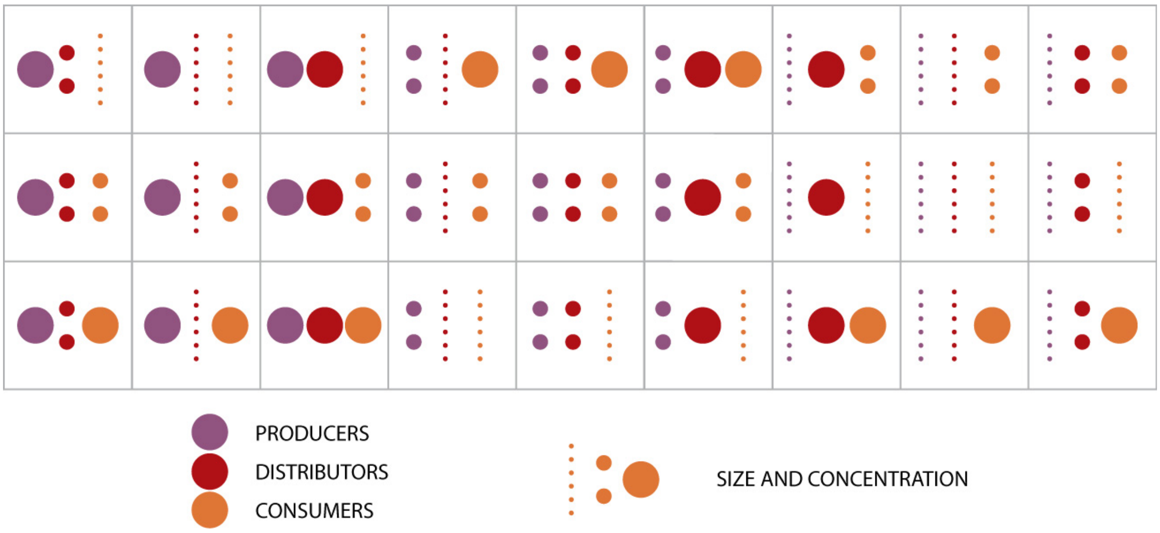


Fig. 4.4 Trophic business models

It was therefore decided to have the entire cycle in one screen only, with colourful and simple icons, which should be visualised constantly, and the settings of variables rapidly accessible through pop-up windows. These variables were kept to a minimum by creating groups representing the most commonly found in literature. As well as five impact calculations that could allow designers to have a reference point. Due to data availability, it was decided to perform the calculations of energy use, CO_2 production, and material intensity of solid matter, water and air only. These were graphically represented by analogies with commonly known objects in the form of icons, in order to give a reference of the impact's dimensions. The details about the algorithms developed, calculations methods, data sources and references that Trophec uses are available at the tool's webpage. Next is a description of the tool's structure and working process.

4.2. - INITIAL SCREEN

When developing the tool it was assumed that the creation of a life cycle was a linear process, starting with materials and step-by-step finishing with the recycling. This proved not to be appropriate for the designers' flexible approach, and will be discussed in detail in chapter six sections 6.5 p.219 and 6.7 p.238. Therefore, the first screen showed only the materials icon as active in green, and the rest as inactive in grey, this is a common feature used in interaction design, which helps the user to understand the sequence of actions, figure 4.5.

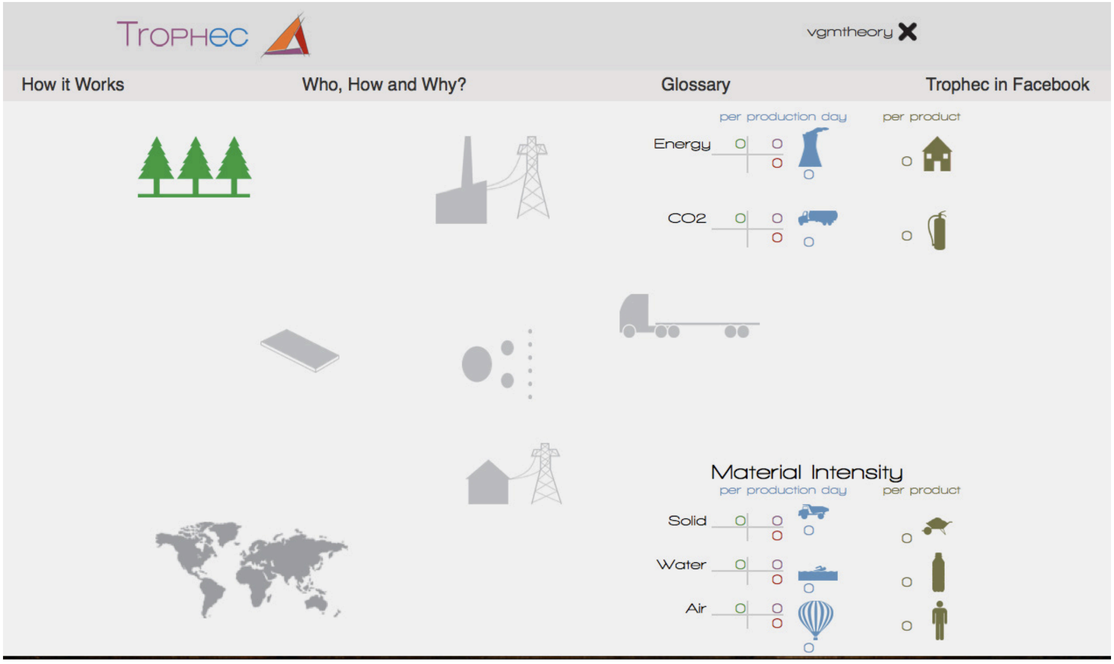


Fig. 4.5 Initial screen

4.3. – MATERIALS

In order to select materials the forest icon had to be selected, a pop-up window displayed the materials available, from top to bottom and left to right figure 4.6: Thermoset, thermoplastic, composite and bioplastic, steel, stainless steel and aluminium, softwood, hardwood, natural fibres and panels, ceramic and glass.

For the next step it was necessary to select the country of origin for that specific material. In the countries' list, an icon displayed in black the regions of the country available to choose, these were obtained in relation to each country's total area, and particular geography (centre, north, east, south, west) figure 4.7.

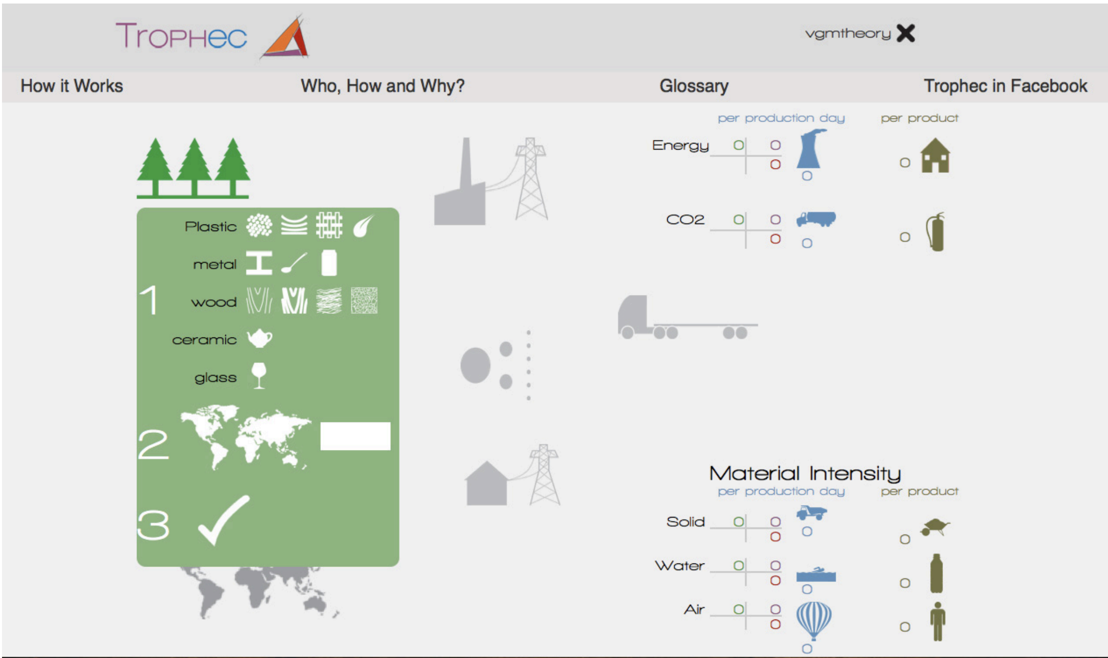


Fig.4.6 Materials pop up window

Fig. 4.7 Detail of country selection

Finally, to add the material and proceed with the process, it was necessary to click on the check icon. It was possible to add up to ten different materials. Once selected, each material had a default input of 5 kilograms, which could be modified at any time with the arrow icons, the amount represented the material per single product.

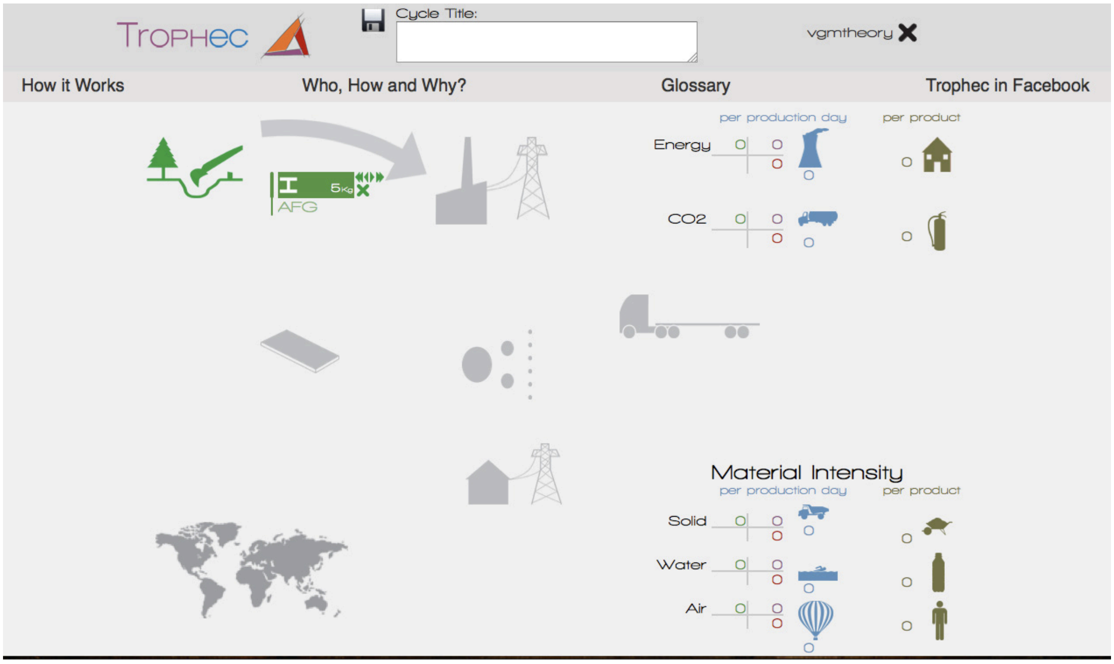


Fig. 4.8 Selected material and next step

4.4. – MANUFACTURING

Once the material(s) were selected, an arrow indicating the next step appeared. In order to select the manufacturing processes, it was necessary to select the factory icon. A pop-up window appeared displaying five processes (forming, cutting, joining, finishing and assembly) these are based on Thompson's (2007) work, and six different work intensities, from left to right: hand: low, medium and high; mechanic: low, medium and high, figure 5.6, which are the result of the analysis of literature on the use of energy in manufacturing processes (Gutowski, Dahmus et al. 2006, Gutowski, Branham et al. 2009).

The next step was to input the number of products to manufacture per day, and the country where the production/assemble would take place. Unlike the treatment of materials, all manufacturing processes had the same country. Once again to add the process it was necessary to click on the check icon. It was possible to add up to ten different manufacturing processes, these are based on Thompson's (2007) work. Each one had a default value of 5 minutes; this being the time the process takes to manufacture a single product. This figure was randomly selected because the user could however modify it at any time with the arrow icons.

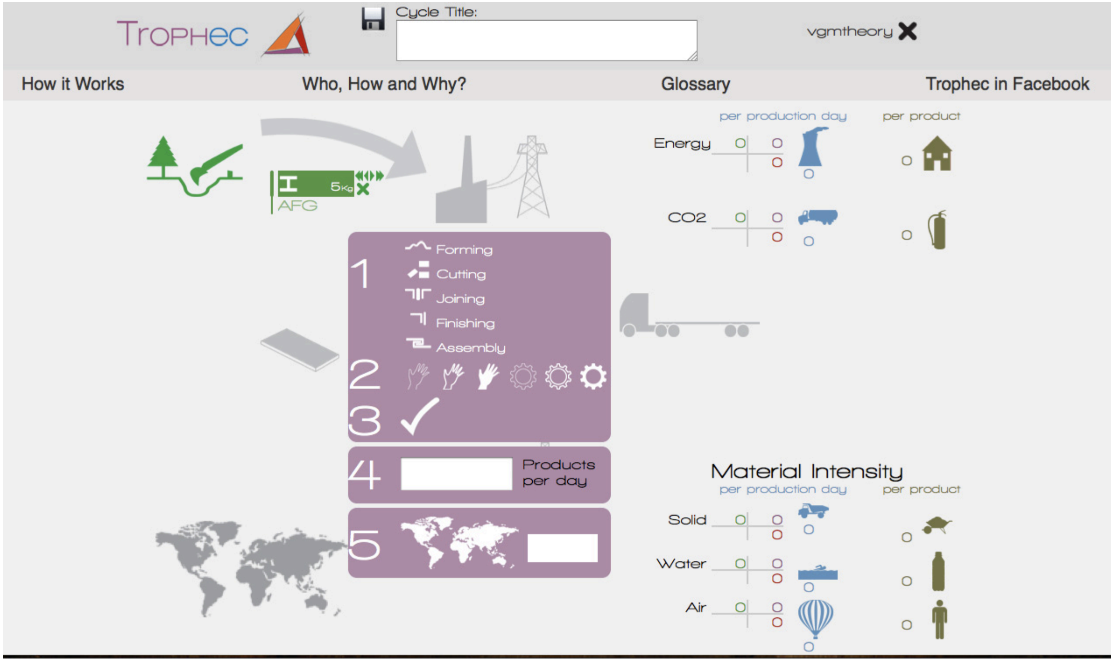


Fig. 4.9 Manufacturing processes pop up window

4.5 – TRANSPORTATION

After the manufacturing processes were selected, an arrow appeared indicating the next step of the cycle. For transportation between manufacturing site and selling point, one of four options had to be selected from the pop-up window, from top to bottom: truck, train, ship and airplane. This four options are one representative of the four categories DEFRA (2011) states in its report. The second and last step was to define the three dimensions of a packaging box for a single product, in order to input the values, the check icon had to be clicked, figure 4.10. The size could be modified at any time with the arrow icons.

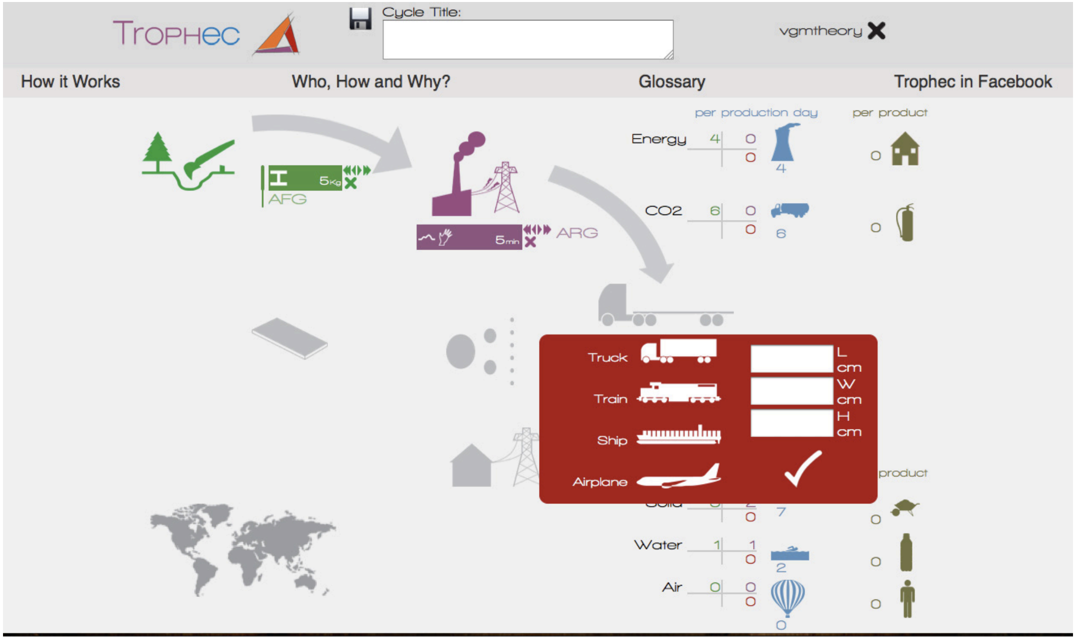


Fig. 4.10 Transportation pop up window

4.6. – USAGE

With the transportation means defined, an arrow appeared indicating the next step of the cycle. The usage pop-up window had four values to define, from top to bottom: total amount of years the product was being designed to perform effectively its function, the total number of uses the product should withstand in its life span, the total amount of petrol (gasoline) in litres the product will consume in its life span, and the total amount of electricity in watts per hour the product will consume in its life span, these variables were determined after analysis and reflection of related literature (Brezet and van Hemel 1997, Wimmer and Züst 2001, Ritthoff, Rohn et al. 2002, Bhamra and Lofthouse 2007, Thorpe 2007, Vezzoli and Manzini 2008, Fuad-Luke 2009). It was also necessary to select a country and click on the check icon, figure 4.11. All values could be modified at any time with the arrow icons.

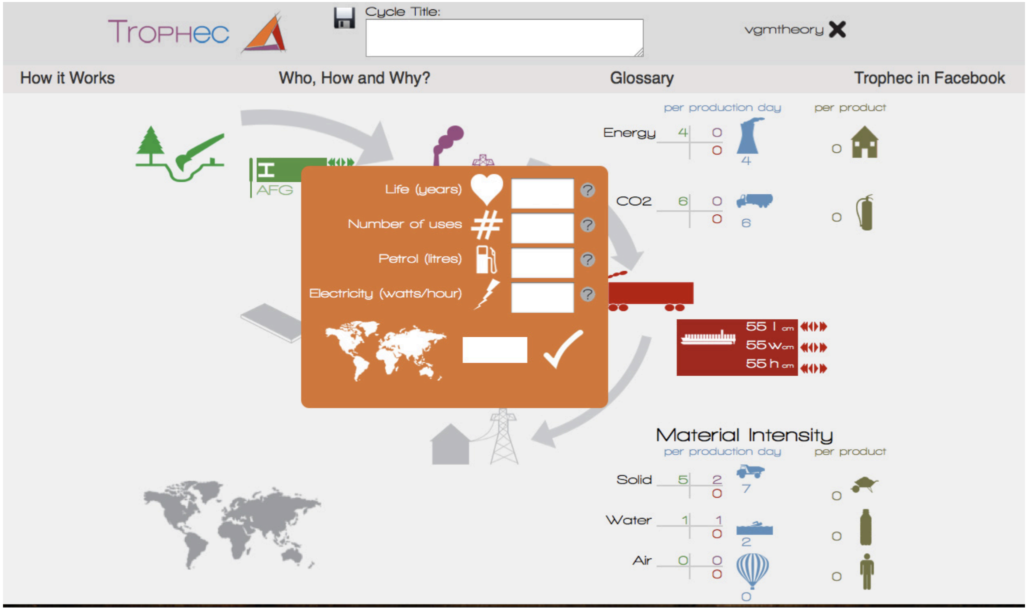


Fig. 4.11 Usage pop up window

4.7. – RECYCLING

Again, with the usage defined, an arrow appeared directing to the next and last step - recycling. In this pop-up window it was necessary to define the percentage of the product which would end up going to or returning from: consumers, distributors, producers, compost or landfill - which correspond to the other four steps of the life cycle, plus landfill, in this way the user could relate the selections made in materials and determine the percentage of recycling for each destiny. All values could be modified at any time with the arrow icons. Also in this step, in order to set the desired values, it was necessary to click the check icon, figure 4.12.

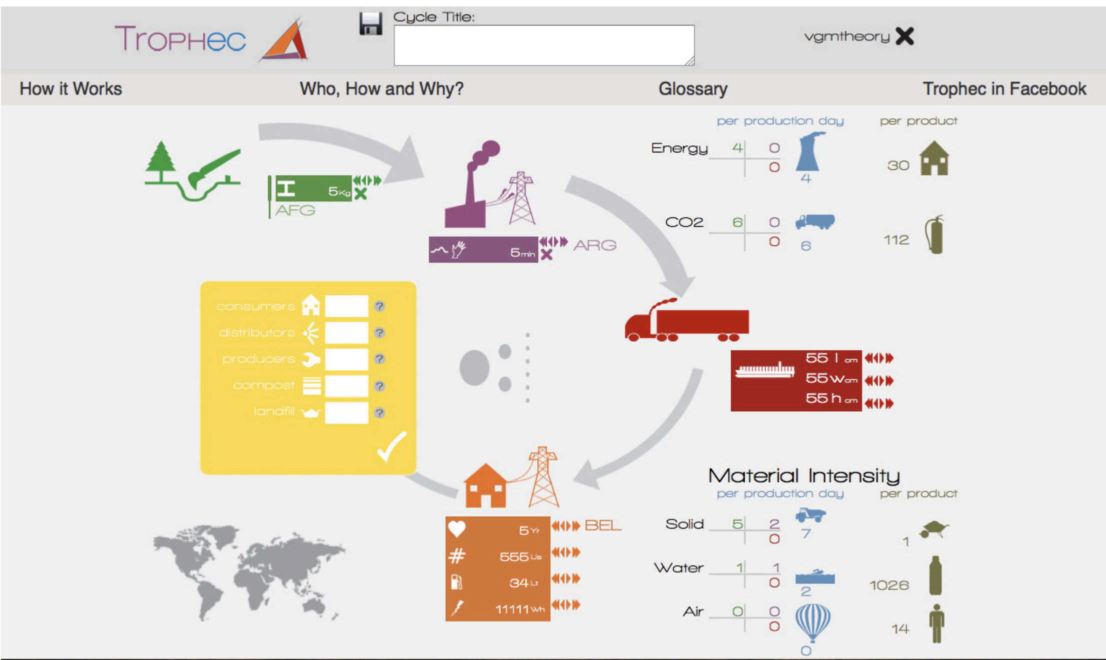


Fig. 4.12 Recycling pop up window

4.8. - BUSINESS MODEL

One important characteristic, discussed previously, was the concept of the size of the businesses, in relation to their context and their resources. The name of the soft modelling tool 'Trophec' comes from the concept of 'Trophic Economics', as mentioned before. Trophic Economics refers to the creation of businesses that achieve: size and distribution accordingly to the resources locally available, empower diversity by adapting business models to local characteristics and needs without neglecting possible global strategies.

The last step in the creation of the cycle was to select one of the different business models inspired on the Trophic Economic principles. Nevertheless, communicating this complex and immature concept in the tests proved not to be viable; in the pilot and first test participants dedicated too much time to understand it, and the flow of the process was severely disrupted. Therefore, the participants of subsequent test were informed about it, but asked not to spend too much time on it, as it was not the main focus of the research. There were 27 different models with different options of size and distribution of the production, distribution and consumption for the business model, figure 4.13. It did not affect in any way the calculations of the cycle.

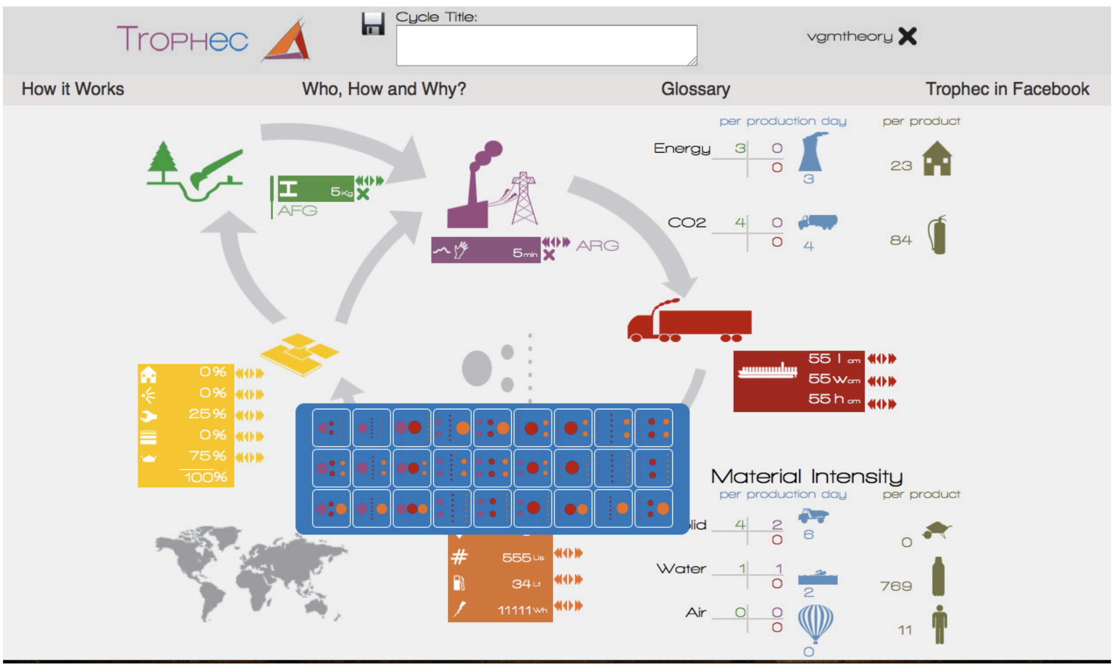


Fig. 4.13 Business model options

4.9. – IMPACT

On the right-hand side of the screen was visualised through icons the impact per one production day and the total impact per single product in terms of use of: energy, generation of CO_2, and material intensity of solid matter, water and air.

A familiar object was used as a reference to more easily understand the size of the impact. Thus, an electricity power plant, a tanker truck, a dump truck, a swimming pool and a hot air balloon was used to represent each value respectively. The number seen alongside each icon stands for the quantity of that object necessary to represent the impact. For each impact category that quantity is divided by its origin in the cycle, which is colour coded accordingly to the cycle icons, plus the total per production day and per product, figure 4.14. The relation between each icon and its represented amount can be seen in figure 4.15.

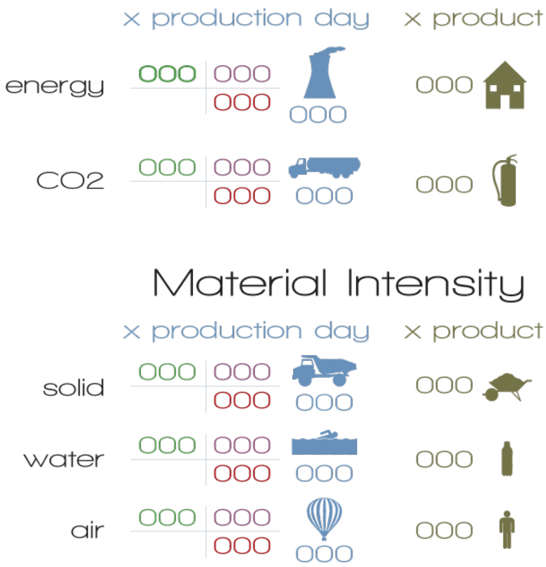


Fig. 4.14 Impact displayed (right side of the main screen)

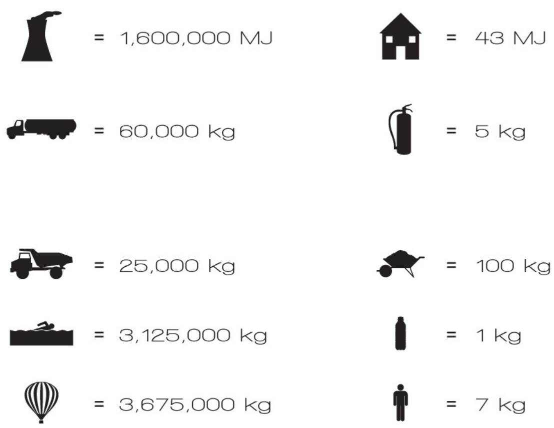


Fig. 4.15 Impact icons' real value

4.10. - STAR GRADING

Using the total amounts for each of the five impacts measured in production per day, a star was displayed in the cycle window. Depending on how low or high the impact was, the star became full or empty, and this had the intention of graphically allow seeing the overall impact of the product, figure 4.16.

Fig. 4.16 Star grading

4.11 - SAVING THE CYCLE AND PDF REPORT

The user had the opportunity to add a short text in order to identify or comment on the cycle, this was possible through a text field located at the top of the screen. This portion also included a 'Save' icon and a PDF generator icon.

The PDF file displayed the exact same cycle screen with detailed information about each step of the cycle.

Included in the PDF file a QR code was generated, with which the PDF file could be retrieved outside of the Trophec environment. This was thought to allow users to share the results with anyone, e.g. in the labels of your products.

4.12. - INFOGRAPHICS SECTION

Once all the steps of the cycle were determined, a green map of the World was displayed on the bottom left side of the main screen. By clicking on it, a new different screen showed practical information about the countries selected in the cycle, figure 4.17.

BIODIVERSITY

The total number of species in that particular country and the World average (WRI 2012).

SLAVERY AND CHILD LABOUR

The Tier created by The Central Intelligence Agency's (CIA), grades the countries that have, or do not have policies and programmes to prevent person trafficking (slavery) and child labour. The scale goes from one to three, being 1 the best and 3 the worst (CIA 2012).

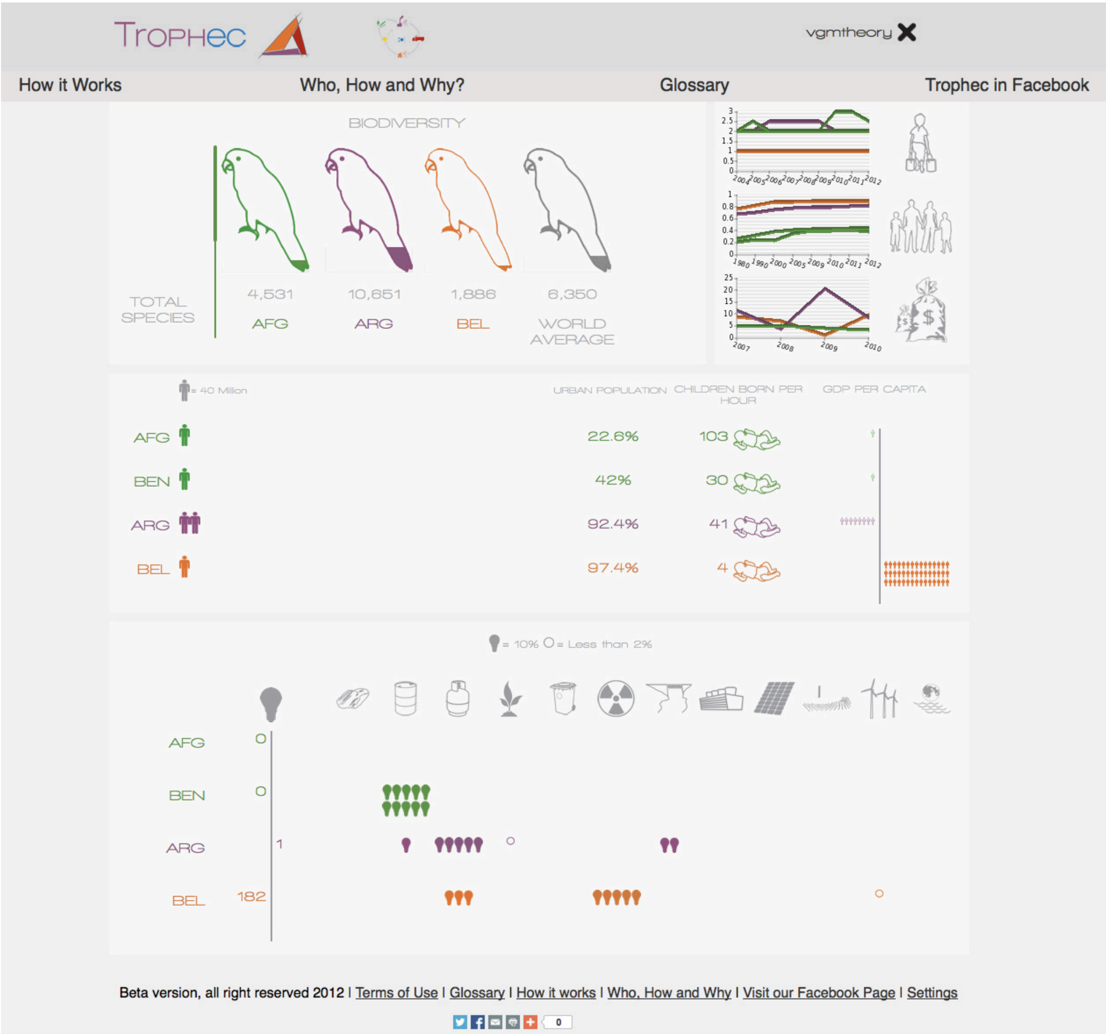


Fig. 4.17 Infographics screen

HUMAN DEVELOPMENT INDEX

Created by the United Nations, this is a composite of several indicators related to human wellbeing like education, health and gender equity (UNDP 2011).

National GDP

The growth of each country's GDP in the last 4 years (World_Bank 2014).

Population

Displayed for each country was the total number of inhabitants, the percentage living in urban areas, the number of children born per minute and how many times the GDP per capita rises above or falls below the World average (UN 2014, World_Bank 2014).

Energy

It displayed how many times the total electricity consumption per each country is above or below the World average and the sources of its electricity generation (IEA 2014).

To go back to the cycle page, there was a cycle icon button at the top of the screen, figure 4.18.

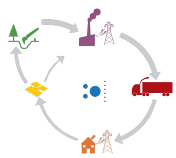


Fig. 4.18 Back to cycle button

Other features

By clicking the username on the top right hand corner, the user's account was displayed, showing all the cycles created, any of which could be retrieved and modified. The PDF could be downloaded at any time, and there was no limit on the number of cycles a user could create, figure 4.19.

The final screen showed through icons all the variables selected, and allowed any changes without losing the visual of the entire cycle, with the impact updating automatically in real time, figure 4.20. In each of the variables of the pop up windows, a question mark was present. This was the access button for the glossary information, displayed in a second pop up window, obscuring and disabling the entire screen. This was meant to focus the attention on the text, and to close it the user had to click anywhere outside the glossary window, figure 4.21. Following the ethics and legal protection for users, researchers and Northumbria, a section with the terms and conditions of use was created.

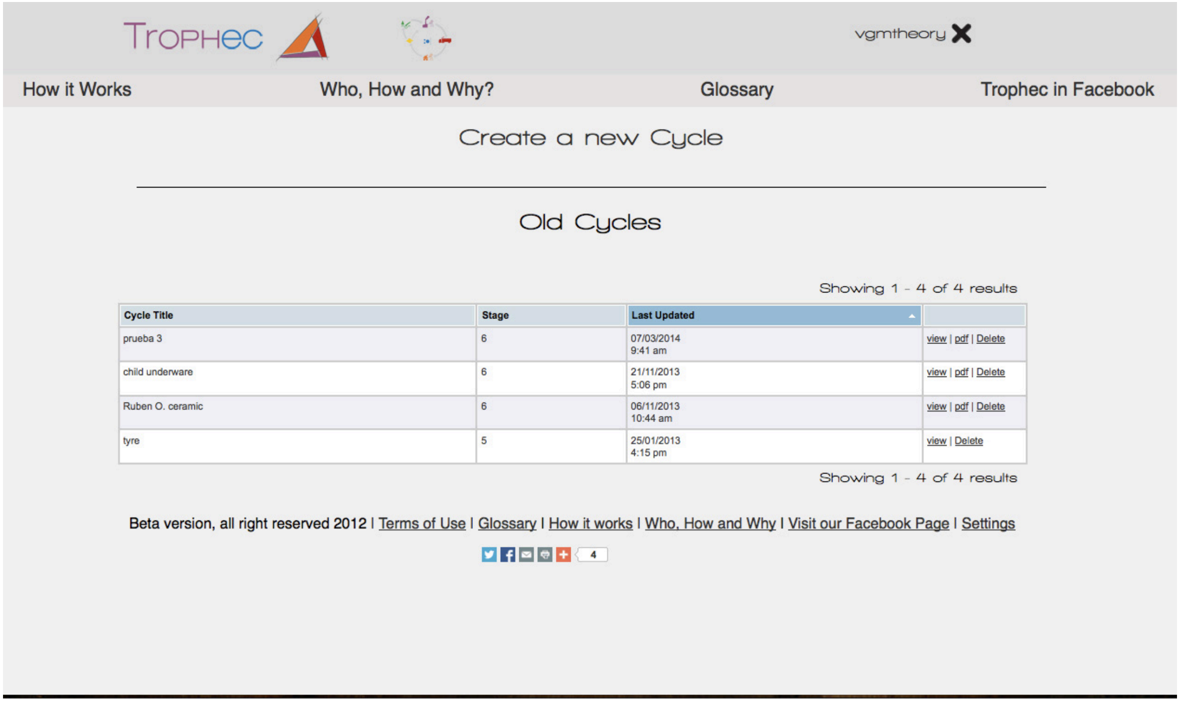


Fig. 4.19 User's account screen

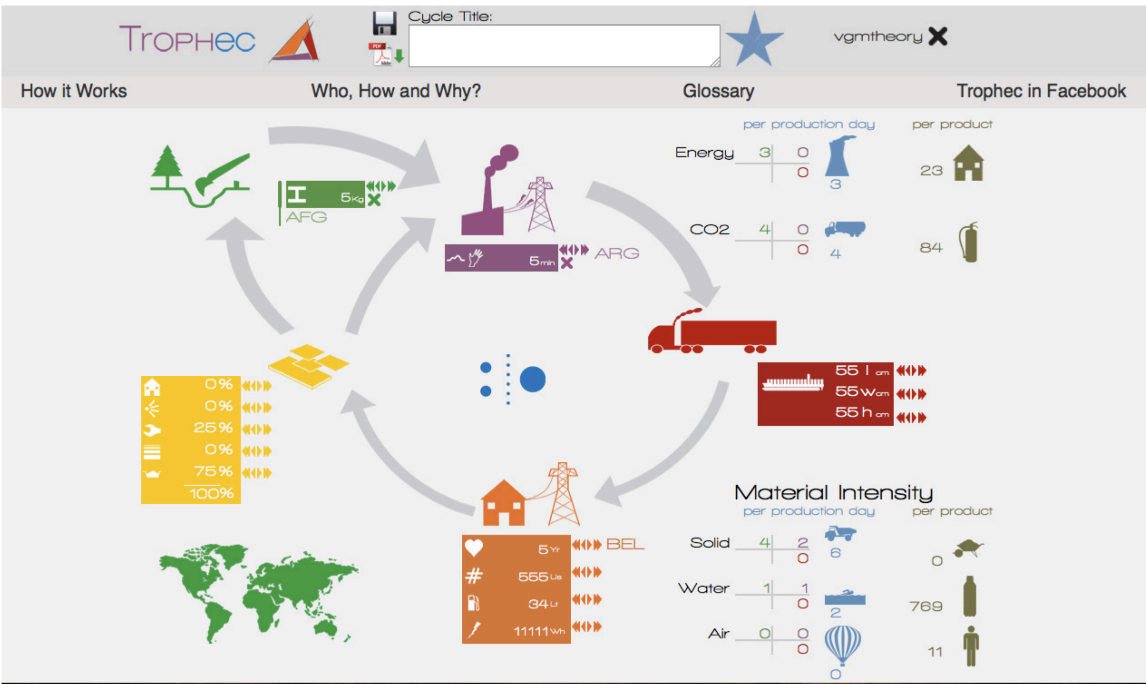


Fig. 4.20 Final screen

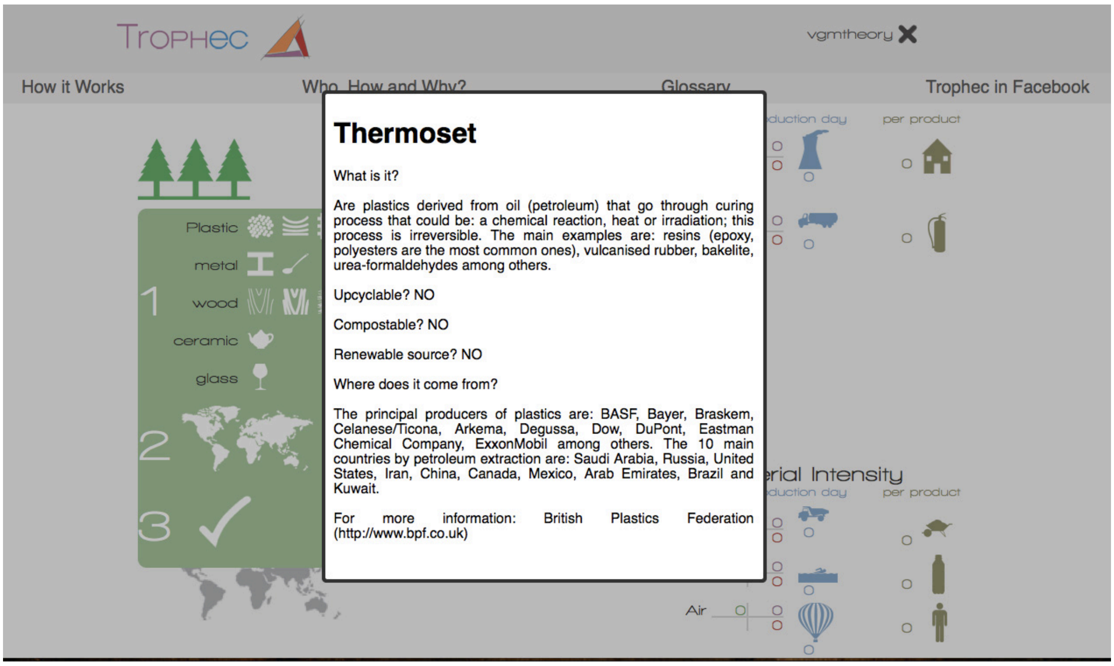


Fig. 4.21 Glossary information displayed

In order to use the free tool, it was necessary to register. To do this, the following data was requested, which only the researcher as administrator had access to: username and password (password was anonymous), forename, surname, email, company or school, position, city and country. In the first login a survey with the following fields had to be completed: how many people work/study in their organisation, in which sector their activities take part, years of personal professional experience, area of specialisation or study, and position in the organisation.

VIDEOS

In order to facilitate the understanding of Trophec's objectives and aims, and to speed up the learning process, three videos were produced (Martinez 2012). One presented the full sequence of a cycle creation step by step; it was 6:22 minutes long. Another presented an overall introduction to Trophec's goals; it was 1:05 long. The third showed the particulars of the star grading and QR code, and the idea of adding these features in the product's label; it was 1:10 minutes long. All three videos were produced in English and Spanish, and uploaded to a YouTube account specifically opened for Trophec (Martinez 2012).

Trophec was entirely designed by the author and programmed by staff from the School of Engineering at Northumbria University. It was financed through funding granted by Northumbria University's Higher Education Innovation Found (HEIF) program. It was hosted with HostPapa web provider, with the URL domain of http://www.trophec.com and available online since September 2012 as a hypothetical tool for the investigative step of this research, no modifications or refinements took place after that date.

CHAPTER 5 - DESCRIPTION OF INVESTIGATION

5.1. – INTRODUCTION

The following chapter of this document will provide a detailed description of the tests performed for the investigation project. Five sessions were held with 22 sets of students and 6 professional designers working individually, involving a total of 70 participants. All sessions took place in the second year of the PhD program, starting with the first session in January and the last in October of the year 2013, with sessions held in the UK, Italy and Mexico.

5.2. - PROTOCOL DESIGN

As mentioned in the previous chapter, Trophec, a soft-modelling tool with the aim of informing designers into the integration of sustainability considerations in early stages of design, was developed for this investigation. The experimental design of the tests was developed to identify, by data triangulation (Martin and Hanington 2012), the activities of the designers' working process with control, and experimental sets. These were used to detect possible differences in the designers' working process, and their reactions to the presence of sustainability information, through a 'raw data' access for some sets, and the information displayed by Trophec for other sets, or the complete absence of it for control sets. In chapter three, section 3.6 p.121 to p.124, it was described how the outcomes of each test informed the researcher about adjustments in the protocol, in figure 5.1 the protocol development is shown through the methods used in each test.

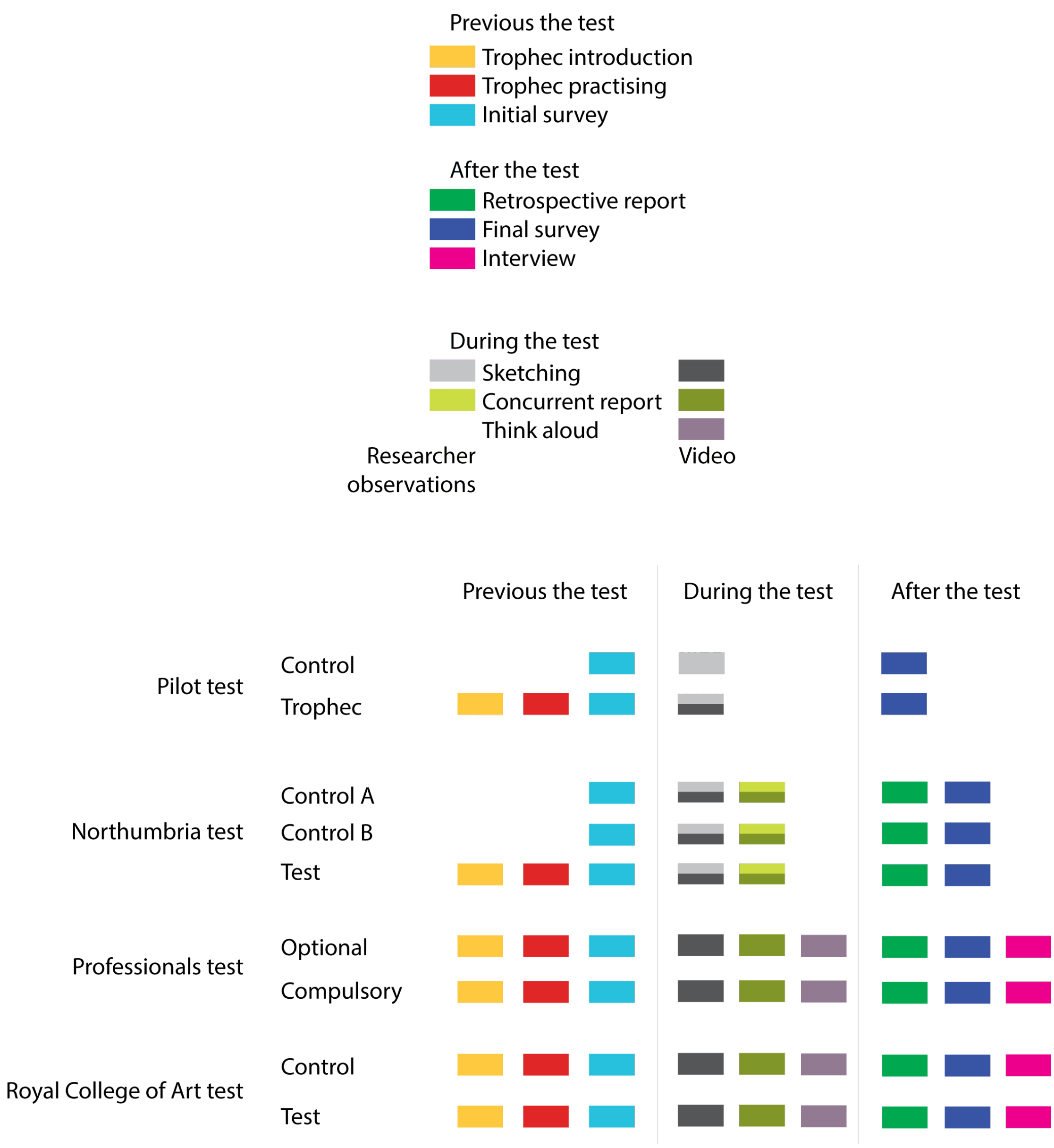


Fig. 5.1 Protocol development flow

5.3. - DESIGN BRIEF

In order to run the tests a design task was necessary. It was decided to use a brief from a current design competition, from an independent and recognised institution in order to avoid any bias. A theme as familiar to the great majority as possible was also sought. A web search of design competitions organised by recognised institutions was performed, and it was finally decided to use NESTA's "Hands off my bike" design challenge. The brief was directly taken from their web page (NESTA 2013):

BRIEF: Hands Off My Bike – Nesta

Bikes have always been targets for thieves. Cyclists are more likely to have their bikes stolen than motorcyclists or car owners. Last year over 500,000 bikes were stolen in the UK (one each minute), with a recovery rate of under 5 per cent. It has been estimated that of the 17 per cent of cyclists that experience bicycle theft, 66 per cent cycle less often and 24 per cent stop altogether.

The Hands Off My Bike Challenge Prize is calling on people from all over the UK to come up with breakthrough innovations to make it more difficult to steal bikes and have the potential to increase numbers of people cycling in the UK.

The winning innovation will be the one that requires the longest time to steal the bike. The innovation will be also judged on the impact on the environment, cost and potential for commercialisation and/or implementation at scale.

Judging Criteria:

- Impact on the environment.
- Costs (to buy or implement - we want to see costs lower than the nearest comparable existing innovation, so the innovation will be attractive to a wide number of cyclists).
- Proposals for implementation and adoption at scale through commercialisation or other means.

The winning innovation will be the one that results in the longest time to steal the bike.

The Judging Panel will also take into consideration the additional criteria on environmental impact, costs and potential for scale listed above.

NESTA's judging criteria was highly appropriate for this research, given its inclusion of systemic and strategic issues, covering not only the functionality and/or aesthetics of an object, but also a specific requirement of the impact on the environment. This is relevant because, as discussed in chapter two section 2.5 p.43, sustainable solutions must address complex problems, and their characteristics are regularly systemic. One of the goals of Trophec is to facilitate a visual perspective of the first hierarchy level of these systemic issues. This criteria was also highly relevant because it was used to ‘grade’ each participant’s final proposal, this grading was performed by three independent and experienced design researchers, they were presented with the sketches of each set, and asked to grade one to five points, where one was ‘not considered’ and five ‘fully considered’. This allowed interesting analysis and comparison that will be discussed in detail in chapter six for each test and lastly as a comparative analysis of all sets, section 6.8 p.264.

5.4. - PILOT TEST

A pilot test was undertaken with four PhD students from Northumbria University’s Department of Design, divided in two sets of two people. One set was video recorded, this was with the intention of registering their conversations, and to later perform a protocol analysis using an already existing coding method. At this point of the research, there was no decision on what coding method to use, or even if it would be necessary to use one, because of the uncertainty regarding the type of reactions and affectations that the test could produce.

The researcher attempted to follow both sets by capturing their activities in a log: the sequence of the sketches, discussion themes or other activities like computer usage. This task proved to be too complex and inaccurate, and could only work efficiently if one researcher is dedicated exclusively to follow only one set.

The first set was for control, to which no instructions or extra material were given. The second set, the experimental one, was introduced to Trophec by watching the 6:22 minute long video describing the tool. The brief was then presented by reading it out loud to both sets, and 30 minutes time allowed for design development.

This test was done one week before the first large scale test. The observations and results of this pilot test were used to inform the refinement of the investigation, but not intended to contribute to the final data. The necessary changes were introduced to the protocol and it was decided to request assistance from other researchers to follow individually the sets for the next session.

5.5. - SESSION ONE, NORTHUMBRIA TEST

This session was held at the Department of Design of Northumbria University on January 31st 2013. Thirty-nine students from the second year of Design for Industry program participated, initially forty-one students attended, but the last two to arrive were dismissed because of the requisite of three participants per set. All participants were called to meet to their regular learning room, and once the starting time arrived the doors were closed and the test started with a brief introduction and explanation about the activities. They were firstly asked to sign the consent forms, then allowed to freely and independently create sets of three persons. This resulted in 13 sets that subsequently were divided into three groups:

- Control A with 4 sets
- Control B with 4 sets
- Experimental T with 5 sets

Besides the author, there were five PhD students, the two tutors of Design for Industry program and one professional designer with 15 years of working experience in product and interior design, plus 5 years of undergraduate teaching Industrial Design. In total there were 12 experienced researchers working as observers, each meant to follow one set only with a log. In order to have the highest similarity in the logs, the researchers were previously trained and informed about the experiment and protocol.

Each researcher had a schedule of activities (see appendix A p.306) and a log, and was instructed to follow their set with one essential focus:

- Capture the sketching activities into their logs, figure 5.2. Emphasising the sequence of sketch creation (McGown, Green et al. 1998, Rodgers, Green et al. 2000).

It was also requested, when possible, to write about other events during the exercise: group discussion themes, silences with no activity, silent-sketching, internet search, etc.

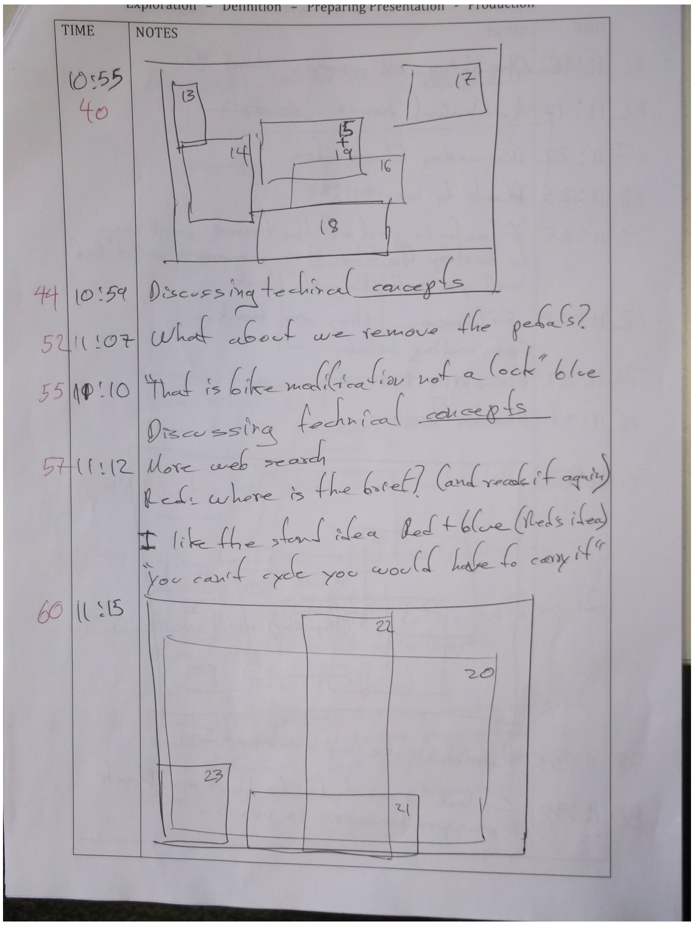


Fig. 5.2 Researcher's Log example

As previously arranged, each researcher knew to which set and group they would belong, and each group had booked an independent room, therefore once the sets were formed, everyone moved to their rooms.

Once in the room the working material was handed to all participants, first an initial survey and a colour pen. Each participant had a different colour pen (Red, Blue and Black) and was instructed not to exchange them; the colour of the pen was also used as a code name for participants, achieving through it the necessary anonymity.

The survey required basic participant data: gender and number of years of professional experience, if any. This was followed by two questions:

Which of the following points you normally consider when designing a new product? You can tick any that may apply

With the possible answers:

- Materials Selection
- Production Processes
- Recycling and Reuse
- Transport Means

- Social Issues
- Increase Product Lifespan
- Reduction of Waste in Production
- Possible Business Systems
- Biodiversity

These options are extracted from Fuad-Luke's (2009) eco-design strategies, and were selected in order to cover all the main steps of Trophec's cycle.

How much time do you regularly spend in each of the following phases of product development?

The answers were related to columns with: 0 days, 1 day, 2 days, 3 days and 5 days:

- Looking for Inspiration Sources
- Identifying the Problem
- Conceptualisation
- Exploration/Refinement
- Definition/Modelling
- Communicating the Idea
- Getting Ready for Production

A sheet of paper was also distributed on each table specifying the set's identification code:

- Control A: A1, A2, A3, A4
- Control B: B1, B2, B3, B4
- Experimental T: T1, T2, T3, T4, T5

The next activity was conducted with the experimental sets only. An introductory Trophec video (6:22 minutes long) was shown to explain in detail all the steps in the creation of a product's cycle. Afterwards, the participants were allowed 10 minutes to play and familiarise themselves with the tool. No further instructions or requests were given regarding the tool, or its usage during the session. The rest of the test was exactly the same for all participants.

Once the surveys were completed and collected, the design brief was read aloud, after which a 5-minute session of questions and answers was allowed.

Afterwards, sets of eight working sheets were provided to each set. These were ordered and numbered in sequence, to support the analysis later. All set members were asked to draw only on the front of the working sheets, and to share them collaboratively with their set members, in order to create a continuous dialogue and debate between them. At the top of each of the working sheets was a concurrent report to complete with five boxes aligned horizontally. At the left side, “far” could be read, and at the right “close”, so students were asked to answer the following question each time they started to use a new sheet. A sample of the working sheet can be found in the appendix E p.318.

Please state how far or close your team feels you are to reach your final solution?
At the time of the investigation the term ‘team’ was used, but has since been changed to ‘set’, since team can hold a more specific reference to a level of working together.

One copy of the design brief was also handed out to all sets. For the Control group B only, a sheet of paper with the “raw data” that Trophec uses to make its calculations was also provided. In this sheet there were only Internet addresses organised by categories (the raw data sheet can be consulted in the appendix F p.319). One laptop was made available to each set.

Lastly they were told that the task would last for 1 hour and 40 minutes, and that they would be given an alert five minutes before the end of the allocated time.

Fig. 5.3 One set from group A at work

Once the exercise was finished, the participants were asked to write at the back of each working sheet, on an individual and private basis: ‘whatever you may have thought, or didn’t have the chance to express or draw, at the time that the related sheet was completed. Help yourself to remember what was happening at that point by looking at the content on the front of the sheet. If you can, please state where that particular insight came from." They were allowed 20 minutes for this task.

Once the retrospective report was completed, all participants were asked to respond again to the same initial survey, now as a post-exercise survey.

Finally, there was a debriefing session followed by questions and answers.

All sessions took place as planned and there were no abnormalities or problems to report. All researchers commented that it had been easy to follow their sets.

In all groups, three sets were followed each by one researcher, and the fourth set in each group worked alone and was video recorded, this was randomly selected. This was done primarily with the intention of retrieving the sequence in which the sketches were made, and having their voices registered in case a protocol analysis with the verbalisations coded, which was determined to be informative. Unfortunately there were high levels of environment noise, and the participants' conversations could not be properly transcribed. Furthermore in one of the video recorded sets, all three participants were Chinese, and on many occasions they spoke in their native language.

In the experimental group there was a fifth set, which was left without a researcher to follow, or video recording, just the working sheets. This was the result of not knowing if all the students would be attending the test, and finally having more than the minimum planned (36 students). Taking advantage of the situation, it was decided to include this fifth set in the experimental group under such conditions, following the same principles for having video recorded sets, and sets followed by researchers: to understand until which point the methods, and triangulation of data could be understood and a correlation and generalisation of results created. As well as the possibility of correlating all sets through the data available, in order to attempt drawing more general conclusions thanks to larger samples, the details of this will be discussed in chapter six section 6.2 p.203. In summary, the data generated in each set was:

Control A (no sustainability information)

- A1: Researcher's log, surveys & working sheets
- A2: Video recorded, surveys & working sheets
- A3: Researcher's log, surveys & working sheets
- A4: Researcher's log, surveys & working sheets

Control B ('Raw data' information)

- B1: Video recorded, surveys & working sheets
- B2: Researcher's log, surveys & working sheets
- B3: Researcher's log, surveys & working sheets
- B4: Researcher's log, surveys & working sheets

Experimental T (Trophec presented)

- T1: Researcher's log, surveys & working sheets
- T2: Video recorded, surveys & working sheets
- T3: Researcher's log, surveys & working sheets
- T4: Surveys & working sheets (extra fifth set)
- T5: Researcher's log, surveys & working sheets

5.6. - SETS' DETAIL ON PERFORMANCE AND OUTPUTS

A1

The session started with a discussion and Internet search. For the first hour they used two working sheets with a relatively balanced participation for all members, and searched the internet at least three more times. They reported that they were inspired by spider man's web, optical illusions and woven materials. They used six working sheets in total, the last being their final proposal: a lock hidden in the frame, made out several retractable wires, latching in a numeric combination mechanism built in the frame.

A2

This set used only three working sheets: in the first one a higher proportion of written analysis was made, in the second one a search for concepts with some written statements, and the last one their final proposal: a parking lot with bulky metallic 'rings' for locking the bike using the saddler's tube, together with a special fixing lock in it. They reported in sheet two to have felt 'lost', and in the third to have attempted to make the idea fit with all the brief criteria. The participation tended to be higher in Black and Red members. This set used the internet sporadically throughout the entire test, each participant with their own laptop. Red reported to have seen videos and benchmark of analogous products.

A3

In their first working sheet a wide analysis of existing products, analogous products and materials was made, mainly captured through written statements. This set also performed several Internet searches and video watching. In the second working sheet, also heavily written, a list of possible ideas and a first configuration of the final idea can be found. The third is for development of the final idea and the fourth, and last, for its presentation. Their final idea is a flexible, retractable net, made out of Kevlar and plastics, allowing a compact size for transportation and a large coverage of the bike. The thief would need to make a great number of cuts to get the bike. The participation tended to be higher in Black and Red members.

A4

This set started by analysing the problems and possible solutions, as well as existing products through an Internet search in Google images. They reported that this step had felt 'time consuming' as well as the need for more research. Next followed a period of idea generation, proposals relating to the helmet, collapsible wheels and wire-locks are distinguishable. They report a 'triangular lock', worked on since working sheet four. This was the only team complaining about the use of A4 size to sketch and the sequencing of them, using six sheets in total. The final idea is two 'clamps', one on each wheel, and a retractable wire, allowing the user to enclose any part of the bike. The participation tended to be higher in Black and Red members.

B1

In their first two working sheets they analysed why bikes get stolen as well as some possible strategies, of which is mainly written. After this followed a period of concept generation where the focus seemed to be in locking both frame and wheels. Finally they explored the idea and defined some details about the mechanism. In working sheets six and seven a different concept emerged but did not prosper, and they finally produced a lock with three 'hooking' devices, one rigid and two flexible, in order to fix the wheel and the frame to a fence of bicycle parking. They used eight working sheets. This set used the Internet first on YouTube, searching for evidence of how thieves steal bicycles, and throughout the rest of the test several times for existing solutions with Google Images, only one occasion with web search.

B2

The researcher following this set, reported an initial discussion where many ideas were mentioned, but not all captured in sketches. These included: render bike useless, lock on handlebar, dummy lock to confuse thief, etc. This was also done while searching in the Internet and watching some videos. This set seemed to struggled to define a final concept, which was developed in the final 20 minutes of the test. This was a 'cut' in the frame, transforming it in a lock by itself, disguised/hidden by the bike air pump. They used seven working sheets.

B3

This set started with an analysis about why people steal bikes, followed by a rich period of idea generation, where the main driver seems to have been deterring the theft with an alarm, a tracking device, by removing bike parts, spraying substances and even explosions. For these last two some concerns were expressed about regulations against harming the thief. The final idea was a device locking the wheels on the spokes, and a wire between them to lock the bicycle to a fence or post. They used seven working sheets.

B4

With an initial brainstorm they defined that the solution could be a parking station or a locking device, and with some Internet search they also thought about deterring the thief and using alternative materials. Subsequently, they fixed on the idea of not giving space for the thief to cut the lock and started exploring the concept. In a combination of material, form and function, they devised a lock, similar to a belt that can be stretched in order to avoid any space to fit in a cutter. This set used the highest number of working sheets, ten in total.

T1

They began the test by doing a mind map of all types of locks, with only one member using the Internet in this point. This was followed by a period of conceptualisation, where many ideas were conceived, including the following: to 'wrap' the bike, to cover it with a 'big lock', an anti-theft paint, or disassembling the bike to make it useless. Halfway through the test, Blue proposed a radical idea, retrospectively reported in sheet five: 'concluded that we could go further than just designing a lock, maybe a system instead'. He later proposed, inspired in videos watched in Internet, a parking service, which slowly evolved into the final idea: rooftop parking, with an automated carrying system outside the building. They did not use Trophec at all, and worked in nine sheets in total.

T2

This set showed a predominance of Red and Blue, and from the first working sheet pursued an exploration of parking systems, focusing on locking both frame and wheels. Their final idea is a system of two massive posts, connected by three metallic bars, which open when a coin is inserted and a timer set. With these three bars the bike is locked on the spot where the user wants. This set used only three working sheets and Trophec was used once the final idea was established. Throughout the entire test they used Google images to search for existing solutions.

T3

The test started immediately with a conceptualisation phase, seemingly dominated with parking systems ideas. Once the final idea was selected they used Internet to benchmark it. They used only four working sheets and were the only set that produced one idea about the packaging of their product, which was a set of three 'bracelets', one for securing the frame to a post, and the other two to lock the wheels to the frame. This set used Trophec once the final idea was established.

T4

This set started with a brainstorming and an Internet search for existing solutions, which produced several ideas such as: using the pedals to lock the wheels, using a 'snake lock' (a long wire to wrap the bike in multiple places), and using the chain or the handlebar to lock the bicycle. They reported being interested in not adding extra parts as their sustainability exploration. Their final idea is a handlebar that can be used as padlock by removing it from its original position. They used six working sheets and Trophec once the final idea was established.

T5

They started by doing an analysis of lock problems; this was captured in written statements in working sheet one, after which the set struggled throughout the test to define one final idea to develop. They produced many concepts, not all captured in sketches, including: a wearable lock, removing the pedals, destroying part of the bike if stolen, or a long wire to wrap the bike. With some signs of frustration they reached the end of the test without an outcome. In the final ten minutes Blue made a unilateral decision about what idea to develop, which was unopposed and became their final proposal: a sturdy lock in the form of a double bracelet. While doing this, Black opens Trophec and defines one cycle. They used six working sheets.

5.7. - PROFESSIONAL DESIGNERS

As it was previously explained, the professional designers were contacted through the researcher's network. Pro 01 and 02 were based in Italy and the rest in Mexico.

Pro 01 and 02 test took place on 29th and 30th June 2013 respectively. A Panasonic video camera model PV-GS80 was used, and the video captured in a Mini DVM60 cassette, later downloaded to a Hard Drive at Northumbria's media laboratory in form of a MP4 file. The location was properly illuminated and because of the summer season, the window had to be opened to maintain proper ventilation. A feint background noise of children playing is some times heard, but in general the video and audio quality was excellent, and did not present any problems for transcription and analysis.

In order to introduce Trophec, three videos were produced previously, two of them one-minute long, the first explaining the general objective of Trophec and the second one about the QR code and star grading produced for each cycle. The third video was 6:22 minute long, and described all the steps and variables available in Trophec, as well as the characteristics of the infographics page and the downloadable PDF.

For the test in Italy only the 6:22 minute video was shown. The period to use Trophec was allocated but it was optional, the participants were asked to use it only if they thought it could make any contribution to their work.

Considering the limited time availability of the professional designers, on this occasion the test was constrained to the minimum time thought to be acceptable: each of the three design steps was 20 minutes long, and Trophec usage 10 minutes after step one and two. This made a total of 1 hour and 20 minutes, plus interview.

PROFESSIONAL 01

Pro 01, male, has 12 years of working experience, an undergraduate degree in mechanical engineering, and a graduate degree (masters) in transportation design. In the last 6 years he has worked as designer in a large manufacturing company developing furniture fittings.

Pro 01 was the only professional who did not perform the test in his working place; the location where the test took place was the working office of professional designer 02.

Phase one, conceptualisation

Pro 01 began by reading the brief, declaring that it contained a contradiction: namely it requested a low cost, low environmental impact and commercialisation capacities – attributes which are not easy to combine. He states therefore that the solution must be implemented to the current construction of bikes.

These reflections lead on to a series of analysis about why and how bicycles are stolen, which is represented with a figural representation and a number of written descriptions. All this lasted for the first ten minutes of the test, and the participant used only one working sheet, in which he reported feeling far from the final solution. No computer or any external information source was used. The last statement in this period was: 'eco-sustainable? Let's make it from cardboard'.

This was followed by almost one minute of silence and inactivity, in which the participant read what he wrote in working sheet 01. Immediately after, the participant took the working sheet 02, and directly started writing concepts for solving the design problem. This lasted the remaining 10 minutes of test's phase one, where the participant produced four different ideas: explosive indelible paint (mark both the thief and bicycle), octopus chain (secure several points of the bicycle), steel bag and the removal of a part of the bicycle. These ideas were all presented by way of written descriptions, with only two being accompanied by figural representations. The first action in working sheet 02 was crossing the 'far' box. Once all the concepts were described, the participant crossed the continuous two following boxes.

Trophec's first exploration

Once the time for phase one was finished the researcher intervened and asked the participant to stop and introduced the next step. The researcher gave the option of using Trophec, to which the participant replied that it was not useful because he 'had no idea to assess', that all of his concepts were not feasible for eco-design, and that he needed first to know what to do and how to do it, before thinking on materials or processes. During the dialogue with the researcher, the participant stated that another idea could be to create a register of all the bicycles parts.

Second phase, refinement

The researcher then introduced the second phase of the test. The participant took working sheet 03 and wrote the mentioned idea, and developed it to what came to be the final proposal: stamping a serial number on the bicycle frame, which would be hidden by the painting, and readable only with a specific device. Each bicycle should then be registered to a particular user, but no development of the necessary system to do this was mentioned.

In the last section of working sheet 03 the idea of complementing the stamped serial number was added, with a hidden microchip to connect the bike with the GPS system, and a mobile phone application that would alert the user of any undesirable movement of the bike. All of this was written, no figural representations were produced. Between the 29th and 31st minute the participant stopped and read working sheets 01 and 02, and later the brief. This action did not seem to have influenced any particular decision or development. In working sheet 03 the 'close' box was crossed.

Before taking working sheet 04, the participant asked himself 'how do you make something to cost less than a padlock that already costs one euro?' Immediately after, he read the brief for more than one minute, when putting down the brief he stated 'ok I will develop this idea', referring to the serial number stamped and hidden. Therefore, the final decisive moment was in minute 36:46, and the entire working sheet number 04 was used to summarise the final concept, all written, no figural representations were created. In working sheet 04 the 'close' box was crossed.

Trophec's second exploration

When the 20 minutes for the second phase were finished, the researcher introduced the option to use Trophec, to which the participant replied by explaining that his idea did not involve a new object, but was a step in the manufacturing process of the bicycles. His rationale was that thieves would always find a way to break any padlock, and that it was better to find a way to deter, to discourage the act of stealing instead of mechanically fixing the bike. Therefore, the participant stated that Trophec was of no use at that point.

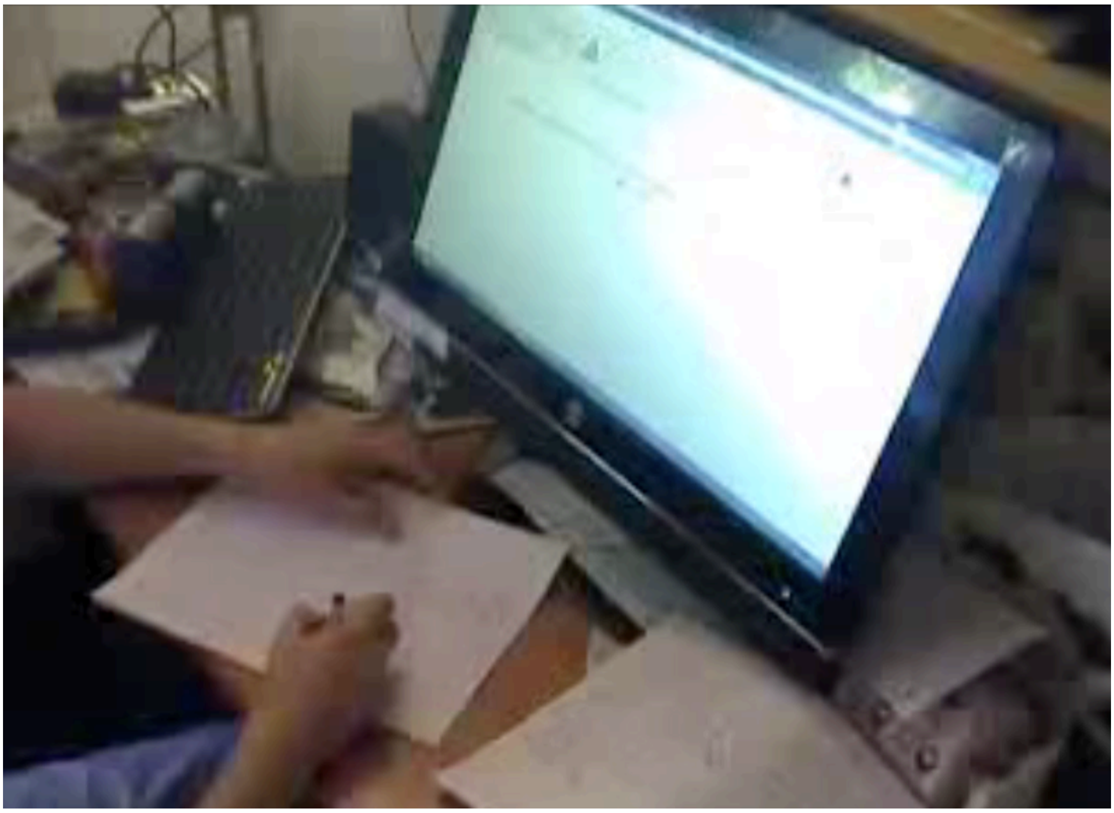


Fig. 5.4 Sample of Pro 01 at work

Third phase, definition

The researcher then introduced the third phase (definition). To this, the participant replied that he already finished, also declaring that he lacked the knowledge to develop the entire proposal.

Interview

The researcher then proceeded to the unstructured interview, asking first at which point of the design process the participant would take into consideration the materials and manufacturing processes. He replied that for his final idea there were no materials to select, and no particular manufacturing processes to add, other than the regular ones to produce a bicycle. The same question was repeated but in relation to a product of his regular job, the participant answered that he would use it between exploration and getting ready for production, but with changes to the software, because, he stated, a designer in a large company does not decide all the steps in a product's life cycle. He then continued to describe the complexity of the procedures within his company to select, buy, manufacture and take decisions. All processes are divided by departments, and there is no one person who controls or is aware of the entire process. Furthermore, there are some automatic actions over which no one has direct control. Therefore, he said, software like Trophec should be able to be completed by the relevant department responsible at each stage.

The total time of the test was 46:33 minutes, 63:07 minutes when the interview was included.

PROFESSIONAL 02

Pro 02, male, has a graduate degree in transportation design and 23 years of working experience, including 11 years as designer and project manager in a multinational car manufacturing company, and the last 12 years as an independent consultant mainly in the transportation sector. Pro 02 performed the test in his daily working place.

Phase one, conceptualisation

Pro 02 began by reading the brief and reflecting on the idea of why someone wants to steal a bicycle, and if it can be substituted with something else that is harder to steal. Then he proceeded to write in working sheet 01 the different reasons for what a bicycle is used, and the problems why people may not use them. Just before minute five, the participant identified different alternatives for the bicycle that, according to his perception, were more difficult to steal. This exercise took the participant to verbalise one initial idea, which was, if someone attempted to steal, the bicycle would be destroyed. Immediately after he wondered if the brief was explicit on the need to use the existing bicycles, or if it was open to substitute them with something different. He therefore re-read the brief for almost two minutes, and stated that according to the brief the bicycles must be the same, it must be an add-on accessory, concluding that all work so far was rendered useless.

From this last reasoning he arrived at the conclusion that the final proposal depended on who is the client, if it is a bicycle or accessory manufacturer, all of which is captured in writing in the working sheet 01. In it, the box in between far and close was crossed.

Working sheet 02 was initially used at minute 15 by writing that if his ‘client’ was an accessory company, the base idea is to make it ‘useless’ to steal the bike. At that moment he decides to search in the Internet what already exists for this purpose. He uses exclusively Google images, and finds satellite antitheft devices. He also states that he does not find anything interesting, but looking at the images does inspire him, because he could see that there are two types of theft - if the frame is protected, the wheels are stolen, and vice versa. Therefore, looking at the images has given him ‘little’.

The time for the first phase of the test was running out, so he finalises writing two product categories he wants to develop: a ‘physical’ product and other ‘deceiving’, both for an ‘accessory’ company only, and stating that he will develop two concepts for each category. In working sheet 02 the ‘close’ box was crossed.

Trophec’s first exploration

Next, the researcher introduced the Trophec phase, where again, the chance to use it or not was open. The participant decided not to use it, declaring that for what he was doing it was not useful.

Second phase, refinement

Therefore, the second phase was introduced. The participant restarted with the two product categories and used the following 15 minutes to develop four different concepts, two for each category; for the ‘physical’ category, a lock with acid inside that will destroy the bicycle if stolen, and a structural one involving a long chain locking several points of the bicycle. For the ‘deceiving’ category, a fake floor lock, and after having difficulties to find a second one, he proposes an ‘electronic’ solution, a GPS device hidden inside the frame. He used working sheet 03, for the ‘deceiving’ floor lock product, and working sheet 04 for the ‘physic’ products. Only three figural representations were produced. In both, working sheet 03 and 04, the ‘close’ box was crossed.

At minute 35, the researcher announced that five more minutes remained for the second phase, to which the participant replied saying that he had finished and could move to the next phase.

Trophec’s second exploration

The researcher therefore introduced the second chance to use Trophec if considered useful or necessary. The participant decided again not to use it, declaring that it would be ‘adding another complication’.

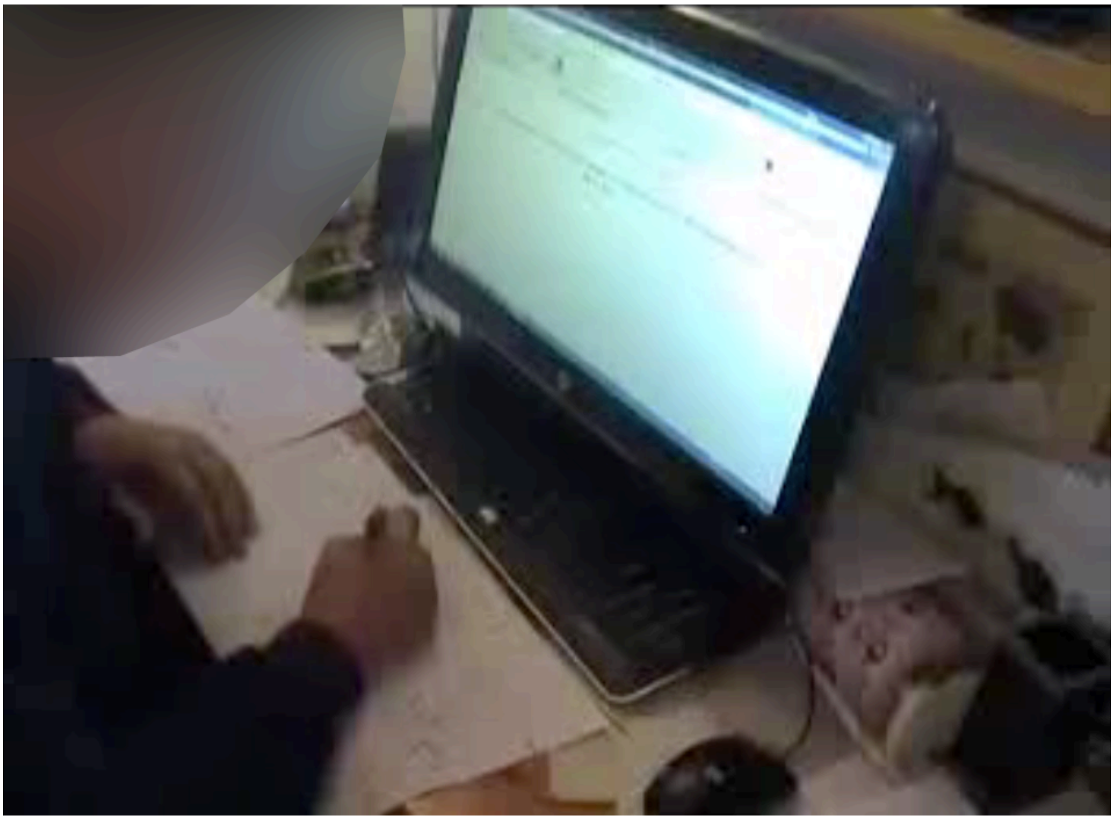


Fig. 5.5 Sample of Pro 02 at work

Third phase, definition

The third phase started at minute 37:20, the participant used working sheets 05, 06 and 07 to define some details of the four different concepts he had ideated previously.

Interview

The researcher concluded with the unstructured interview, where the participant firstly was asked why he thought Trophec, and all the sustainability information that it delivers was not useful for him. The participant replied saying that because the clients do not want it, they consider it a waste of time and money; and because designers have a 'background culture' where certain things are simply not considered. He reflected in silence for a few seconds and then stated that, a system like Trophec, should not be only directed to designers, but also to marketers, because sustainability must start as part of the company's culture, and communicate to the users the product's value, therefore the companies will request designers to include sustainability in their designs. The dialogue in the interview led to the researcher showing the two one-minute videos. The participant commented that it would have been useful to see them together with the longer video, because this one was too focused on the functionality, and lacked a wider perspective and goal. The purpose of this research was focused on identifying possible influences of the tool, not assessing the learning speed on the part of the user. For these reasons the researcher decided to show all three videos in future tests.

The total time of the test was 58:06 minutes, and including the interview was 72:26 minutes.

The next four professional designers tests took place in Mexico in mid October 2013, after the test was performed at the Royal College of Art (described later in this chapter). All three introductory videos where shown before the test. The time for using Trophec was equally allocated, but because of the behaviour showed by Pro01 and Pro02 as well as the experimental sets of Northumbria test that did not use the tool, this time its use was not optional. The participants were asked to either create a cycle, or just navigate through the information in the glossary if they thought the prior was not possible.

The camera used was a FLIP Video Ultra PSV-552, which automatically saves in digital MP4 format file. In all cases the researcher verified that the illumination and ventilation were appropriate, no difficulties or technical problematic situations emerged, all videos had good visual and audio quality, and did not present any problems for transcription or analysis.

PROFESSIONAL 03

Pro 03, male, has 15 years of working experience with an undergraduate degree in Industrial Design, all his professional career has worked as an independent designer, consultant and entrepreneur, designing and marketing his own products. Pro 03 is a well-known and successful designer in his home country, with international experience and reputation. Pro 03 performed the test in his office.

Phase one, conceptualisation

Pro 03 started with a simple and clear reasoning: a prohibitionist approach that locking bikes and putting bars would never work. What is needed is to work with the minds of the people, 'instead of locking the bike, why we don't put a lock to the thief's mind?' 'The bicycles should not be chained, we just need to let thieves know that the bike has a tracking device'. The participant then defined the use of a GPS device, connected to an application in a mobile phone. In less than two minutes he defined the idea he wanted to develop, all of it with figural representations, with some writing notes complementing the sketches being made. In working sheet 01 the 'close' box was crossed.

The participant then used working sheet 02 and 03 to reflect on previous existing solutions, and that thieves had always managed to break all of them, concluding that working on the mind of thieves was the best way to proceed. He stated that thinking in those old type of solutions made them feel far from an optimal solution, so he crossed working sheet 02 ‘far’ box, no box in working sheet 03 was crossed. All these arguments were expressed mainly with figural representations.

After using working sheet 04, the participant immediately started exploring the selected idea, initially crossing the box in mid way between far and close, but after the embodiment of the proposal he crossed the ´close´ box. Then the participant stopped and the researcher asked him if he wanted to keep on developing concepts, or move to the next phase, to which he replied he wished to move forward on the test.

Trophec’s first exploration

The participant was then asked to use Trophec, to create a cycle or simply to gather information about materials or processes using the glossary, but 10 minutes had to be used with Trophec.

The first action was to use working sheet 05 to identify a series of components he needed for his product. No box of the far – close concurrent report was crossed on this sheet. Then he selected thermoset plastic without any verbalised reasoning, and when deciding the country of origin, he selected China and used an expression in Spanish (common in Mexico only), ‘ya ni modo’, that refers to consciously select something which is not the best, and accepting it as not having any other option.

For the second material the participant wanted to input in Trophec the electronic devices, microchips for GPS signals, which are made essentially of silicon. Trophec does not have this type of materials, and the researcher reacted saying that ceramics was the closest thing, this based on the type of material, a mineral, not renewable and not recyclable as main characteristics. He accepted the recommendation and selected again China as country of origin.

For the plastics he selected forming, with hand medium intensity, afterwards taking his calculator to determine the amount produced in one day, once again China is selected as manufacturing country.

For the transportation he decides to use an airplane, giving the small size of the product as the reason. The dimensions are chosen very quickly.

The life span is calculated to be five years, the total uses is calculated by first stating that the bicycle will be parked four times a day, for five years, giving a total of 7,300, but Trophec allows a maximum of 5,000. No petrol or electricity was needed, as the device will work with batteries recharged with a solar panel. Country of use is Great Britain.

For the recycling he reflects for a few seconds, and realises that the plastic can be recycled, so he selects 50% for producers, and the microchips and batteries, ‘not being so good’, to landfill, the other 50%.

Second phase, refinement

Once the ten minutes with Trophec was finished, the researcher introduced the second phase. Pro 03 used the working sheet 06 to explore some issues related to the characteristics of bicycles (frame made with tubes), and how this could relate to his product. He then decided to look for images of bicycles in the Internet, searching for the best place to locate his device. This was done exclusively using images in Google. This gave him enough inspiration, and when returning to the working sheet, he started to define the details of his design. In working sheet 06 the previous box to ‘close’ was crossed.

Afterwards, working sheets 07 and 08 were used to quickly define technical and aesthetic aspects of the final proposal. One issue prompted in this process, the participant realised that it would be necessary to have certain technical knowledge to install his device, so he mentioned the need to add ‘a different business model’ and include a service. When finished the participant again stopped and the researcher asked him to return to Trophec.

Trophec’s second exploration

The participant decided to re-open the previous cycle, declaring that it was still pretty much the same, but when looking at the materials, he saw 200 grams for thermoset plastics, and decided to remove it because it exceeded in weight his needs, and decided to just keep ‘the most polluting one’ the ceramics.

He quickly checked the rest of the cycle making no changes, except in the recycling step where he realised that embedding the electronic device in resin inside the bicycles’ tube, in order to make it impossible to remove, making the previous consideration of recycling no longer possible. The final configuration was 30% to producers, and 70% to landfill, expressing again ‘ya ni modo’.

Later Pro 03 decided to look at Trophec's infographic section, and noticed that China had a high probability of child labour, to which he again repeated the Spanish expression when saying: 'we will put Chinese children to work ya ni modo'.

Third phase, definition

Next the third phase was introduced; the first activity was to go out to the street to measure a bicycle. On returning to his desk he measured an AA battery too. These measurements were captured in working sheet 9.

With the measurements, the participant proceeded to create a computer 3D model of his product using the software 'MODO', it took him 15 minutes to do this. With this software he also produced several renders. In minute 59 he used Google images to search for an image of a lateral view of a bicycle. He imported this image, and the renders into Keynote software, and used it to build the final presentation board of his product. He used Google images twice more, once to get a frontal view of a mobile phone, and the second time to get an image of an icon of a person riding a bicycle. These two images were used to show the application for mobile devices to which the product is connected. He finally wrote a small statement explaining the concept. This last working sheet was saved in PDF format and emailed to the researcher.

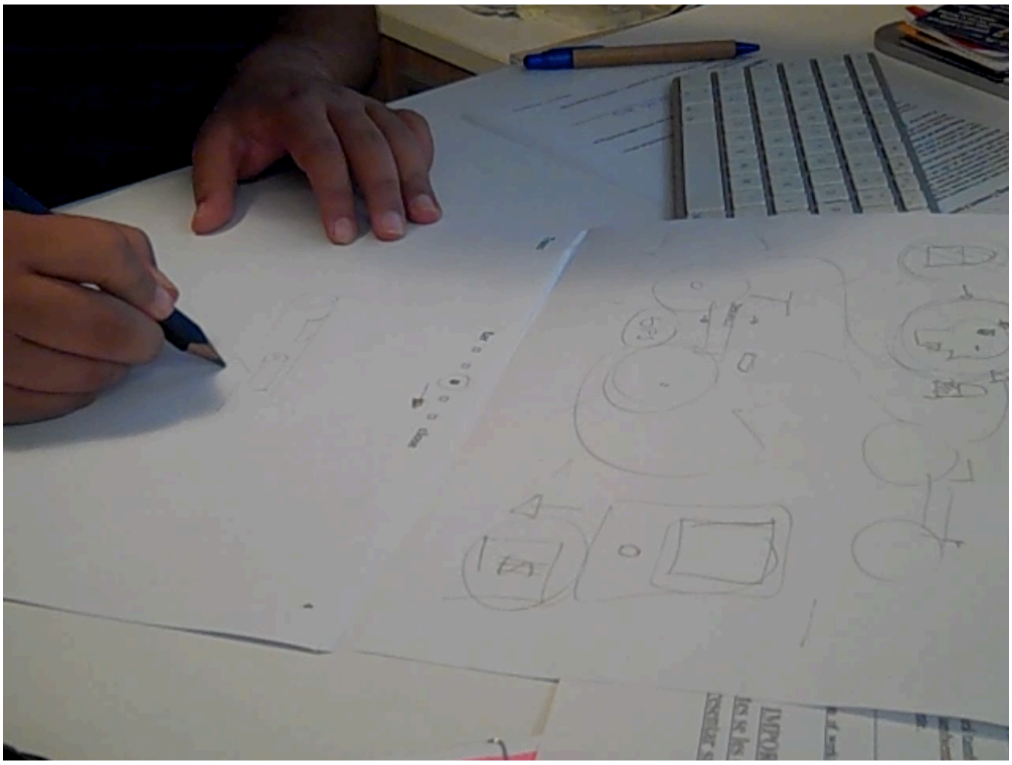


Fig. 5.6 Sample of Pro 03 at work

Interview

Finally the unstructured interview was held, the researcher firstly asked about the selection of China and why the 'ya ni modo', that the sentence expressed acknowledgment of it being wrong, but accepting it. The participant replied that there is a dual feeling, he knows its wrong, but he also knows that for a longer project he would had the chance to investigate providers, and choose one that is not using child labour. He also stated that there is also a reason of viability, as he knows that providers in China will deliver on time and to quality.

Later the researcher asked, in relation to his decision of adding a service to the product and intervening in the business model, if in his professional practice he normally had the chance to do this with clients. He replied that it was possible, but in cases when it was stated initially that it would be part of the project to design a service and collaborate with marketing. Then he was asked if in any of these he had been asked to include sustainability considerations, to which the answer was plainly no. Lastly the researcher asked when, in a new product development, he thought he could use Trophec, he said that once the design was 'frozen' and they were planning production.

The total time of the test was 71:54 minutes, and including the interview 80:36 minutes.

PROFESSIONAL 04

Pro 04, male, has 15 years of working experience with an undergraduate degree in Industrial Design. In the last 10 years he has worked as an independent consultant developing a broad range of products for clients in several countries. Pro 04 performed the test in his office.

Phase one, conceptualisation

Pro 04 started questioning whether the bicycle had to belong to a user or not. The researcher replied saying that the brief does not specify that. He next stated that it was necessary to understand where the real problem was, using working sheet 01 to write this and creating two lists, one of the product possible problems and other about the problems created by the context.

Once he had completed this, he identified two possible ways to find solutions: one was to deter the theft, and the other to attack the black market. For the former he ideated three possible product categories: unattractive bike, a high security system and an identification serial number; and for the latter only one: to destroy the bike. All these statements were written, and no figural representations were made. In working sheet 01 the ‘far’ box was crossed.

From working sheet one, the participant decided to follow the concept of ‘unattractive’ for thieves. In working sheet 02 he wrote a list of possible ways to make a bicycle unattractive, and next a series of reflections on how to achieve them, together with their pros and cons. These reflections lead him to identify materials and manufacturing processes, and ‘unique’ as concepts to develop. Later with these he ideates the concept of a manual to build you own bike, with materials and processes each person could use at their home. He identified the need to collaborate with a mechanical engineer, to be sure that the materials and processes would be feasible. In working sheet 02 the following box after ‘far’ was crossed.

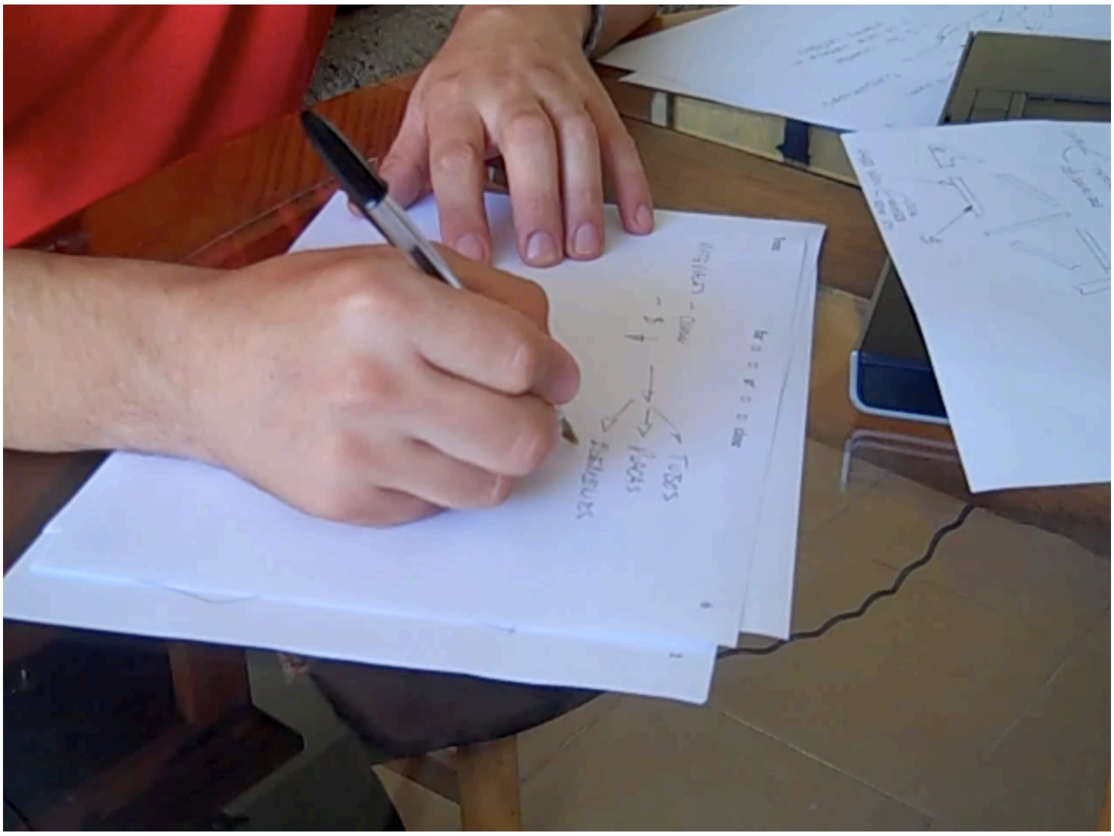


Fig. 5.7 Sample of Pro 04 at work

Trophec’s first exploration

The participant was requested to use Trophec, like Pro 03, to create a cycle or just get information about materials, processes, countries, etc.

When the participant was about to select materials, he said that the software was structured to create products from zero, but what about when creating a product from other products?

The first material selected was a natural fibre. To assist in the selection of the country, he opened the material's glossary information, finding that Mexico is a producer of natural fibres. He therefore chose Mexico, stating that he supposed that the project was for Mexico.

After selecting materials, Pro 04 tried to define the recycling process. As Trophec builds the cycles with a linear process, this cannot be done until defining all previous steps.

Once in manufacturing he first opened the glossary information of 'forming', and after reading he selected it, together with mechanical light intensity, and Mexico as the manufacturing country. He also added 'cutting' and 'joining' with hand high intensity for both of them.

For the transportation method he first asked whether more than one could but selected but this was not possible. Finally he chose truck and input the packaging dimensions, making assumptions and stating that was 'absolutely random'.

When facing the usage characteristics he stated that without more development in the design process he was writing what he 'would like to', rather than what he 'already knew'. He decided 15 years as life span and 3000 uses. Neither petrol nor electricity is used; Mexico was also selected in this step.

At the recycling step he first opened the glossary information of 'consumers'. On closing it he stated that for them, he would expect recycling to be high, and supposed some parts could also be returned to distributors or producers. Then he realised that the material selection he had thought to make implied the use of resin (a thermoset not recyclable), thus making it 'technically difficult to return'. Finally he selected 75% to consumers, 5% to distributors, 5% to producers, 15% to compost and nil to landfill.
Once the cycle was complete the participant stated that this exercise helped him realise that what he had chosen at the beginning (fibres embedded in resin), did not allow him to have the recycling process he wanted (compost).

Second phase, refinement

The second phase followed, with the participant taking the working sheet 03 and crossing the 'far' box while stating that at that moment, he felt further away than when he started. He next wrote the three concepts previously identified, that he wanted to work with:

‘home-made’, ‘materials’ and ‘unique’ (through a combination of home-made pieces, bicycle parts and other products).

In the 20 minutes of the second phase, he used working sheets 03, 04, 05, 06 and 07 to explore these three concepts, which are very closely related. These working sheets were crossed in the ‘far’ box first (in 03), later in the following box (04 and 05), and finally in mid way between far and close (in 06 and 07).

Trophec’s second exploration

The time for the second phase ended and the participant was asked to return to Trophec, with the option to create a new cycle, modify the previous one, or simply use Trophec to get more information from its glossary.

He decided to continue with the previous one and made some modifications. The first action was on materials. He opened the glossary information of ‘bioplastics’ and finally selected it saying that it was what he was looking for. Later he opened it again to look for which countries it could be brought from, selecting Mexico because up to date there are only a small number of companies producing them, and no particular country of manufacture.

Acknowledging that adding another material meant the need to add another manufacturing process, he added ‘forming’ with mechanical light intensity.

Pro 04 changed from truck to train while stating that he would like to have something ‘better’ but knowing the reality of the country, he said it was not very feasible.

He then decided to create a new cycle, first selecting hard wood and opening its glossary information, after that selected Mexico as country of origin. At this point he stated that with Trophec, it was easy to realise how one could complicate things without knowing it, and how because of that ignorance, some decisions would not be the best ones.

For the manufacturing processes he selects cutting, assembly and finishing, all with hand medium intensity, and with Mexico as the manufacturing country. In transport he again selects train and the same packaging measurements as in the previous cycle. He then suggested that Trophec could give indications about the most common measurements of transport containers, so when defining packaging, it would indicate how many products would fit, and what changes in packaging dimensions would make the transportation more efficient.

In usage characteristics he defines 20 years of life span, 5,000 uses, no petrol or electricity and Mexico. For recycling he selects 80% to consumers and 20% to compost.

Third phase, definition

Pro 04 started using working sheet 08, and stated that the solution could be a 'kit', therefore he identifies three different types of components: bicycle parts that one must buy because they cannot be manufactured at home, like the chain or breaks; parts that could be bought but are meant for other purposes, like pipe joints, cables, tubes/pipes, wooden sticks, etc; and parts that could be manufactured at home by recycling material from other products, and with processes specifically developed for it, all contained in the manual. In working sheet 09 the participant made a figural representation of these concepts. Both sheets were marked in the mid way box between far and close.

Finally the participant used working sheet 10 to describe the idea of 'one cycle inside the other', referring to the recycling of other products, in order to obtain the materials to build the bicycle, which lead to complex reflections about how a product could become part of others and so on, in continuous exchanges, therefore 'a product never dies, it just incorporates into other'.

Interview

The interview started with the question of how often, in his professional practice, he had the chance to intervene in the business model, to go beyond just the product development. He replied that he has a good chance to do this, but very low interest from the clients; the only ones allowing this are small technological start-ups, the average entrepreneur, he said, 'does not have the openness to understand it'.

The total time of the test was 80:26 minutes, and including the interview 85:17 minutes.

PROFESSIONAL 05

Pro 05, male, has 15 years of working experience, first as designer of a large home appliances manufacturing company, and in the last 8 years as a freelance designer, both mainly in styling new home appliances. He also organises workshops where he teaches drawing techniques in computational environments. Pro 05 performed the test in his office.

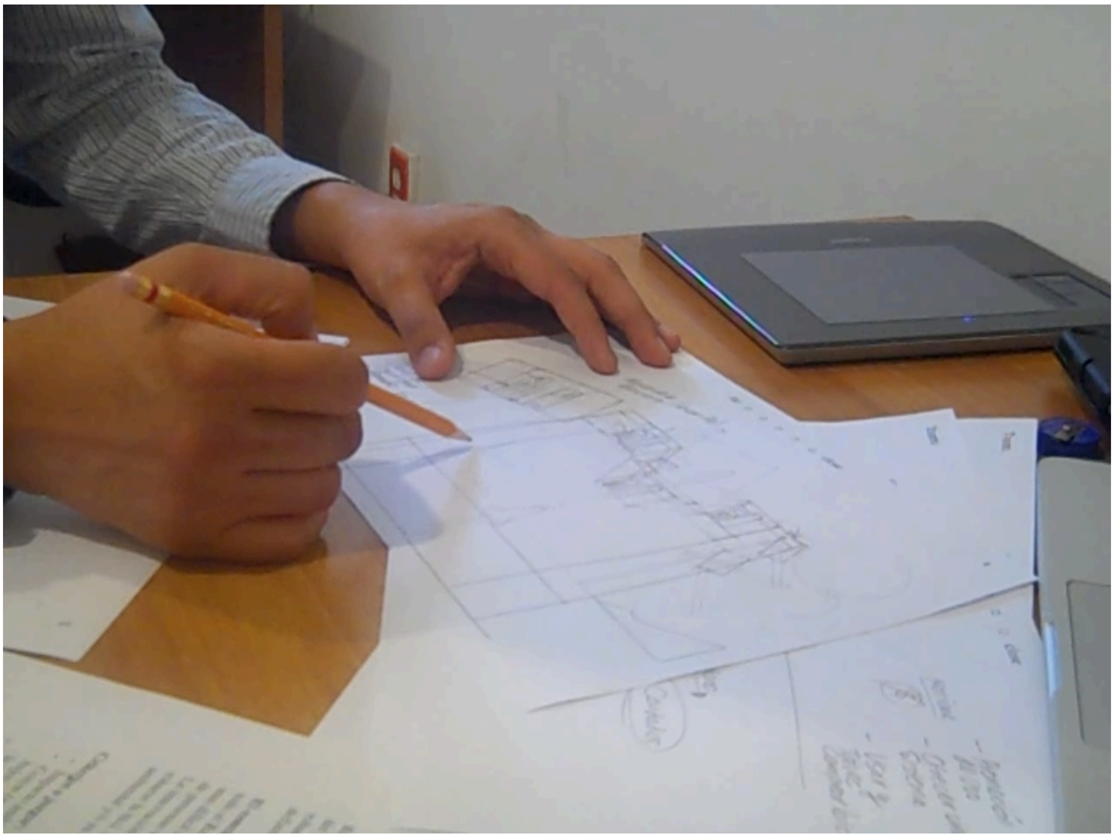


Fig. 5.8 Sample of Pro 04 at work

Phase one, conceptualisation

The participant started the test using the first 25 seconds to read the brief, then he proceeded to write and verbalise, a series of reasoning and arguments about the different actions taken by some governments in providing infrastructure for parking bicycles and moving around the city. All these are captured in working sheet 01, this process lasted the first 5 minutes of the test. In working sheet 01 the ‘far’ box was crossed.

This first process led the participant to identify the need for an integral solution (bikes, parking and streets for bicycles), provided by the government. This can be seen in the first sketches of working sheet 02. By minute six, Pro 05 decided to develop a parking station for bicycles, in order to allow citizens to move without the need to own a lock. The parking station needed to be highly secure and easily accessible.

After this point the participant did not generate any other concept, and started to explore the possible components, and characteristics of the parking station. When recalling personal experiences, he decided to have the bicycles in a vertical position, to avoid using too much space on the pavement, and the use of the fingerprint to activate the lock. For this phase working sheet 03 was also used. It was never mentioned whether this service would have a cost, assuming therefore that it is a free service provided by the government. In both working sheet 02 and 03 the following box after ‘far’ was crossed.

In the last minute of this phase the participant declared the need to 'look' at a bicycle to understand how to develop further his idea. He did this by using Google images, realising that one possible problem was the great diversity in bicycle sizes and shapes.

Trophec's first exploration

The first phase was over and the use of Trophec was introduced. The participant was requested to use it for creating a cycle, or simply to look to the information provided in the glossary.

He decided to start one cycle. The first material he searched for was concrete, which is not included in Trophec, and so the researcher followed the same principle used with Pro 03, informing the participant that, based on the characteristics of non-renewability and non-recyclability, the nearest material to concrete was ceramics.

The first material selected was steel and Mexico as country of origin; next he opened the ceramic's glossary information, after that the hard wood's, finally choosing the latter and Mexico as country of origin.

The participant moves to the manufacturing processes, and after a few seconds of reading the options he opens the glossary information of the hand medium intensity, next the hand high's, after that the mechanical high's. Lastly he selects cutting with hand high intensity and Mexico as manufacturing country.

The next step is transport, for which Pro 05 selects truck. For the packaging dimensions he firstly inputs 500 cm, but Trophec has a limit of 150 cm. Once these are defined, he goes to the usage, selects 15 years as life span. For the number of uses, being a parking station, he deduces that this could be very high, tens of thousands in its life span, so he is informed of the pre-set limit in Trophec of 5000, and sets that maximum. No petrol or electricity is selected, and for country selects Mexico.
In the recycling stage he first defines 30% returning to producers, and 70% going to compost.

Second phase, refinement

The second phase of the test started with another Google images search, looking at bicycle images only. Then he used working sheet 04 to create a much more detailed drawing of the selected concept. Pro 05 was the only participant who erased some sketches and redrew them with modifications. He used this process to define some details of the final product like dimensions, proportions, position of bicycles, and identified the need for a keypad plus the fingerprint scanner. One important definition was the use of wood instead of concrete as he first intended to use. Pro 05 stated that he realised that with concrete, once the parking station came to an end of its useful life, nothing could be done, so he preferred to design a proper structure in wood, giving the same result as concrete but could be recycled or reused. In working sheet 04 the box just before 'close' was crossed.

Trophec's second exploration

The participant first added stainless steel, coming from Mexico. He then added another manufacturing process, that of joining. Before selecting intensity he opened the hand medium glossary information, asking the researcher what 'MJ' meant. After the explanation he selected mechanical medium for the joining process. He added one more, finishing with mechanical medium intensity.

Returning to the usage stage the participant reflects that his product will use electricity, but requested assistance to calculate it. The researcher gives only an example of a typical house light bulb of 60W as a reference point, and asks the participant to open the glossary information to obtain more information, which the participant does. Later when he struggles to understand the difference between watts and watts/hour, the researcher assists him following the example of the house light bulb. This appears to be sufficient and the participant sets his parameters and makes the calculations, reaching the maximum pre-set in Trophec of 999,999 W/h.

Third phase, definition

The third phase was exclusively dedicated to produce one final sketch of the final concept with higher complexity, for which working sheet 05 was used. This time the sketch was in perspective and in greater detail, as well as some text explaining the selected materials, finishing and functions. In working sheet 05 no box was crossed.

Interview

The researcher then proceeded to the interview, the first question being whether he had in his professional practice any chance to propose to his clients any idea beyond the product, to intervene as well in the business model or the service model. The participant gave a definite 'no' to this question, describing his work as purely styling already defined products. The next question was whether if the definition of business model did not belong to the designer, when in the product development and who should take those decisions, he decidedly replied that before the design brief was made.

In response to the question why he chose a parking station rather than exploring individual solutions, he replied that for him the statement in the brief about encouraging people to use the bike was relevant, and his solution was directed to that. Lastly when questioned about the change from concrete to wood, he mentioned that he thought about a solid support for the bicycle's parking station, but when looking to the material characteristics in Trophec, he realised that concrete is not permanent any way, and there was nothing it could be done with it at the end of its life. Therefore his approach was to think which material could be recycled and provide the same performance.

The total time of the test was 80:40 minutes, and including the interview 86:57 minutes.

PROFESSIONAL 06

Pro 06, male, has 23 years of working experience, most of which working for a multinational home appliance manufacturer, being deeply involved in product development from concept design up to manufacturing. Pro 06 performed the test in his daily working office.

Pro 06's test was interrupted for working issues that could not be prevented, furthermore the Internet connection was particularly slow, and Trophec's introductory videos could not be displayed, which resulted in the need for deeper guidance by the researcher when the participant used Trophec. The researcher made an effort to keep this to a minimum, and restricted all interventions to informing the participant about Trophec's characteristics, avoiding at all times inducing or directing the participant's decisions. Despite of the unanticipated events, the characteristics of the process, and the value of testing a professional designer with so much experience, is held to be of high value, therefore considered for analysis.

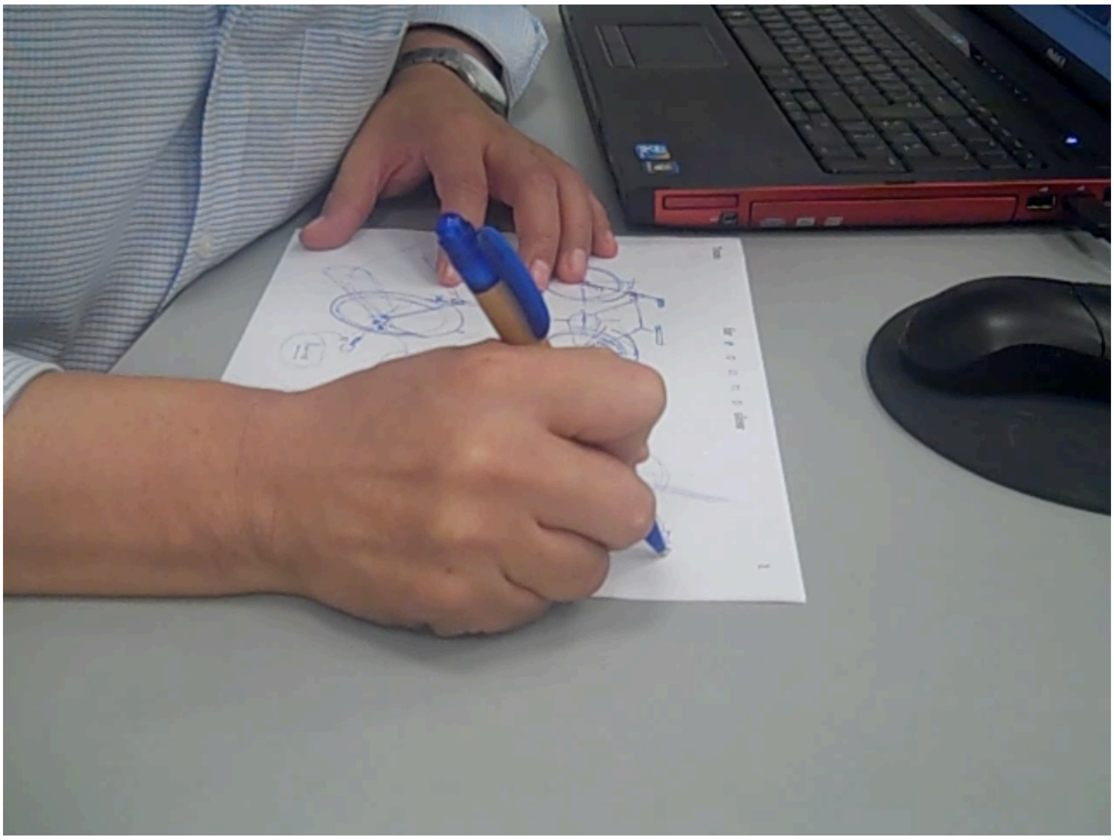


Fig. 5.9 Sample of Pro 06 at work

Phase one, conceptualisation

The test started with an Internet search, exclusively using Google images, with the participant looking for products already in the market, in order to analyse them and look for opportunities. He states that for what he had found, and what he remembers, the solutions are mainly focused on securing the wheels.

After three minutes, he starts to draw a bicycle on working sheet 01. This first sketch is used to reflect on the problem of locking only the wheels, as his stated goal will be to avoid detaching the wheels from the frame. Then he adds to that sketch and transforms it into his first proposal - a built-in bike lock. From that point on, he develops four more independent concepts: an in-wheel GPS device, a foldable scooter, a helmet-lock and a parking system. To capture these concepts he used working sheet 02 too. In working sheet 01 the ‘far’ box was crossed, this being done before any sketch was made. Later in working sheet 02 the box next to ‘far’ was crossed.

Trophec’s first exploration

In the materials section the participant first selected natural fibres, with Mexico as country of origin. Then he moved to the manufacturing processes, where he selected forming, and for the intensity he opened the glossary information of mechanic high, hand medium, hand light, mechanic light, before finally deciding on hand medium and Mexico for manufacturing country.

For the transport stage, the participant first opened the glossary information of the truck, and later selected it. Then he used his hands to imagine the probable size and figure the dimensions of the packaging.

Once again in the usage stage, the participant first opened the glossary information of the life span, after which he defined 10 years of useful life and 3,650 uses (one daily), no petrol or electricity is used and Mexico was selected.

Lastly he defined that his product would be 100% compostable.

Second phase, refinement

The second phase started with the participant reflecting on his five proposals, and stating that using Trophec 'gave him much' with which to choose. He declares that the proposal better 'aligned' to sustainability is the helmet-lock, because is something the user already wears, and later has to carry along, so using the helmet has padlock would avoid the need of buying another product, and carrying the helmet about.

He then uses working sheet 03 to start defining general aspects of the solution, later on working with sheet 04 he redraws it with higher detail, in both working sheets the box next to 'close' is crossed.

After 15 minutes of phase two the participant stops and declares that he has finished. Then the researcher proceeds to the second use of Trophec.

Trophec's second exploration

The participant opened the previous cycle and opened the glossary information on stainless steel, later adding it to his cycle. This material also had Mexico as country of origin.

Next he moves along the entire cycle deciding to leave everything the same, except the recycling, where he decreases the amount going to compost to 90% and adds 10% to producers, although no specific reason was expressed. The rest of the time was used to look at Trophec's infographic section and PDF report.

Third phase, definition

When the researcher attempted to start the third phase the participant stated that he had to attend to a work meeting and so this was not possible.

Interview

The researcher requested – and was permitted - two more minutes to perform the interview. The first question was how much chance he had in his professional practice to go beyond products and get involved in the business model. The reply was simply 'very little'. Next the participant was asked when and whom he thought defined the business model, to which he answered the general management. He later added, as an example, that if he wanted to change to a more sustainable material, he had the chance to propose it, but if the cost was just one more dollar it was surely rejected.

The total time of the test was 54:39 minutes, and including the interview 58:45 minutes.

5.8. - SESSION FOUR, ROYAL COLLEGE OF ART

This series of tests with students were kindly facilitated by the Royal College of Art, and took place the 4th October 2013. Nine students from the first year of the Masters degree program of Transportation Design were available to participate. A Canon camera model XA10 was used, registering directly in High Definition digital format.

The room provided was isolated and well lit, but some quality problems were encountered with sound - the room was very large and empty, so exterior noises echoed and were enhanced by the microphone, causing some verbalisations impossible to distinguish. Other issues like accents, jargon, language skills, or even participants putting their hand in front of their mouth, or talking at the same time, etc. made transcription an extremely difficult and time consuming task. Up to 15 minutes were needed to transcribe 1 minute of recording. It was attempted to edit the sound with professional editing software, in order to improve the quality, but with little success. Nevertheless, the general outcome is believed to be of sufficient quantity and quality to consider the test valid and informative.

RCA 01, CONTROL GROUP

In this set there were two non-native English speakers and one British citizen, nevertheless, the former had a good language level and all three participated actively. Only Red reported to have eight months of professional experience from an internship.

The first set had no particular structure in the session; this was attempting to re-create the conditions of Northumbria's test experimental group 'T', in this test RCA01 functioned as a control group. Therefore there were no specific instructions on when to use Trophec, or steps in design process, just reminders of how much time they had left were given.

This set started by reading and discussing the brief for four minutes, during which time Red made some notes on the brief, this notes referred to the criteria in which they will focus their efforts. The discussion centred on the reasons why a bicycle gets stolen and some references to other products, like the automobile, and later on how to prevent it. In minute 4 Red decided to write down some of these reflections on working sheet 01, and both Blue and Black contributed. In working sheet 01 the 'far' box was crossed.

In minute 14 Red opens Google, they spend almost 8 minutes looking at images of stolen bicycles, making a number of reflections about the parts locked and the parts stolen, as well as the lock types. They read the brief again in order to clarify what was requested and what was not clear. For half of the 8 minutes, an image of a bike in a parking station with both wheels locked was on display. In the discussion Black ideates what would become the central concept of the final proposal - a lock wrapping around the entire bike. The discussion makes a turn when Red proposes a brainstorming, to which Black reacts by writing on working sheet 02 three types of locks; later Red adds some comments to it. In working sheet 02 the 'far' box was crossed.

Fig. 5.10 Sample of RCA 01 at work

While doing so, Blue ideates a lock integrated to the cyclist's clothing. This was just verbalised, with no written or figural representation. A few minutes later, Black through an association to Dyson's vacuum cleaners, ideates a collapsible chain, which drives him to take working sheet 03 and draw his idea, he also prompts a discussion about pro and cons. In working sheet 03 the box mid way between far and close was crossed.

Blue mentions again his lock-clothing idea and Black asks him to draw it, which he does in working sheet 04. Red then argues that both ideas rely on thin and light wires or chains in order to be collapsible or foldable, which he sees it as a good innovation, but needs work around the problem that it can be cut easily.

Red then ideates another concept of a collapsible wheel, which he draws in working sheet 04. Later, inspired by a comment by Blue, Red ideates another concept, the display on the wheel. Both of his concepts are not envisioned to stop theft, but to alert people around that the bicycle is been stolen.

At minute 37 Black recalls having seen a method some retail companies have adopted to deter clothing theft, by introducing a device that sprays a staining liquid, which cannot be easily removed. Blue makes a sketch about this concept in working sheet 04; Black makes the point that it is not a preventing technology, but a deterrent. In working sheet 04 the next box to ‘far’ was crossed.

Next Black takes working sheet 05 and makes three key sketches about a padlock that if cut, a substance (inspired by a squid) will stain both the bike and thief. Red adds some details, and the discussion goes ahead for 12 minutes. Blue does not participate but inspired in the discussion and the iCloud service, proposes the idea of destroying the bike remotely by the user. Before changing working sheet they merge the staining lock, collapsible chain and integrated lock into clothing into one single idea. Blue, as before, does not participate but proposes a final concept: to give free bikes to all, which he considers to be a ‘systemic’ solution. This is rejected because of its high cost. In working sheet 05 the box before ‘close’ was crossed.

All three participants, making explorations about the new concept, used working sheet 06. They performed two quick Internet searches in Google images looking at chain locks and analogous objects. After that moment follows a highly active period that will last till the end of the test, when each participant, using a working sheet individually and contemporaneously, explored different ways to embody the chosen concept. This period is also marked by a noticeable diminution in dialogue. In working sheet 06 and 07 the box before ‘close’ was crossed. In working sheet 08 the ‘close’ box was crossed. This set used 5 extra working sheets making a total of 13.

The researcher announced the end of the test and reactions of surprise and disappointment were displayed. Whilst they could not agree and summarise the process in one final sketch, the final idea was nevertheless clear.

It can be seen that Black had a slight heavier weight in the team, but Red balanced it. Blue also participated but many of his interventions did not produce strong effects, even if sometimes his reflections and comments were interesting.

In the interview the first question was about the fact they did not use Trophec. Black replied that for him the focus of the brief was more about the need of users than any environmental consideration. Red agreed saying that they focused on winning the contest, and that environmental considerations belong to another 'layer', once you have your final 'vision' you 'come back in', seeing it 'far down the process rather than early on'. Blue argued that he did not know if the results offered by Trophec were real. Red added that he thought the test would include a moment at the end to test Trophec. Black agreed and added that first it is about developing concepts and then you use Trophec once the idea has been refined. Unless the brief is 100% about sustainability, 'designers must chose wisely a mid point, then the rest will come after that'.

The total time of the test was 80:23 minutes, and including the interview 84:38 minutes.

RCA 02

In this set all three participants were non-native English speakers, but only one, Black, had a very weak speaking skill, which can clearly be detected in his low participation in the session. Red reported to have three and a half years of professional experience, Blue and Black two years each.

On this occasion and with RCA03, the test had the exact same protocol as the professional designers, three design steps: conceptualisation, refinement and definition, with 20 minutes allocated for each. At the end of step one and two, 10 minutes were dedicated for Trophec, with participants instructed to either create a cycle or explore the information in the glossary, its use not being optional. The goal was to capture possible differences between students and professionals under the exact same protocol.

Phase one, conceptualisation

The test immediately started with Red stating that he believed the solution should be something you carried along with you, something portable. Blue replied saying that it could also be a service provided by the city. Red questioned if the solution could be part of the street. Blue reacted by drawing on working sheet 01 the concept of a bicycle parking on street posts, hanging from a rope, saying that something could be added to the existing post, so it would be an environmentally friendly solution. They proceed to reflect and think of other possible solutions, Blue again proposes a device that cannot be cut, something that the regular cutting devices would not be able to cut. Red then proposes to electrify the bike. Black proposes an underground parking station. After minute five Red reads the brief for two minutes, and returns to the idea of hanging the bikes from the street posts, arguing that the brief requests 'scale of commercialisation', adding that in a city there is always advertisements on streets posts and the bicycles could be inside a box behind them, to which Blue agrees. In working sheet 01 the box next to 'far' was crossed.

Blue takes working sheet 02 and redraws the street post concept in higher detail, exploring possible solutions to some particulars; Red complements the sketch with some details. The time of the first phase is over and the researcher introduces the use of Trophec.

Trophec's first exploration

This set, led by Blue, starts by selecting stainless steel and bioplastic without expressing any particular reason, both from Great Britain. When assigning weight they discussed it making references to the sketches. When moving to the manufacturing step, they select forming. Before choosing intensity they opened the hand light glossary information window, after that mechanic light, and based on this comparison they select hand light and Great Britain for manufacturing country. Finally they add assembly process with hand light intensity again.

For the transportation method they quickly selected truck, and when defining dimensions they use their hands to simulate the size of the product and figure the amount to input.

Blue, when faced the requirement of life span verbalised: 'this could last for a long time' and proposed ten years, which all participants accepted. He also proposed 5,000 uses. There was no use of electricity or petrol, and Great Britain as place for usage.

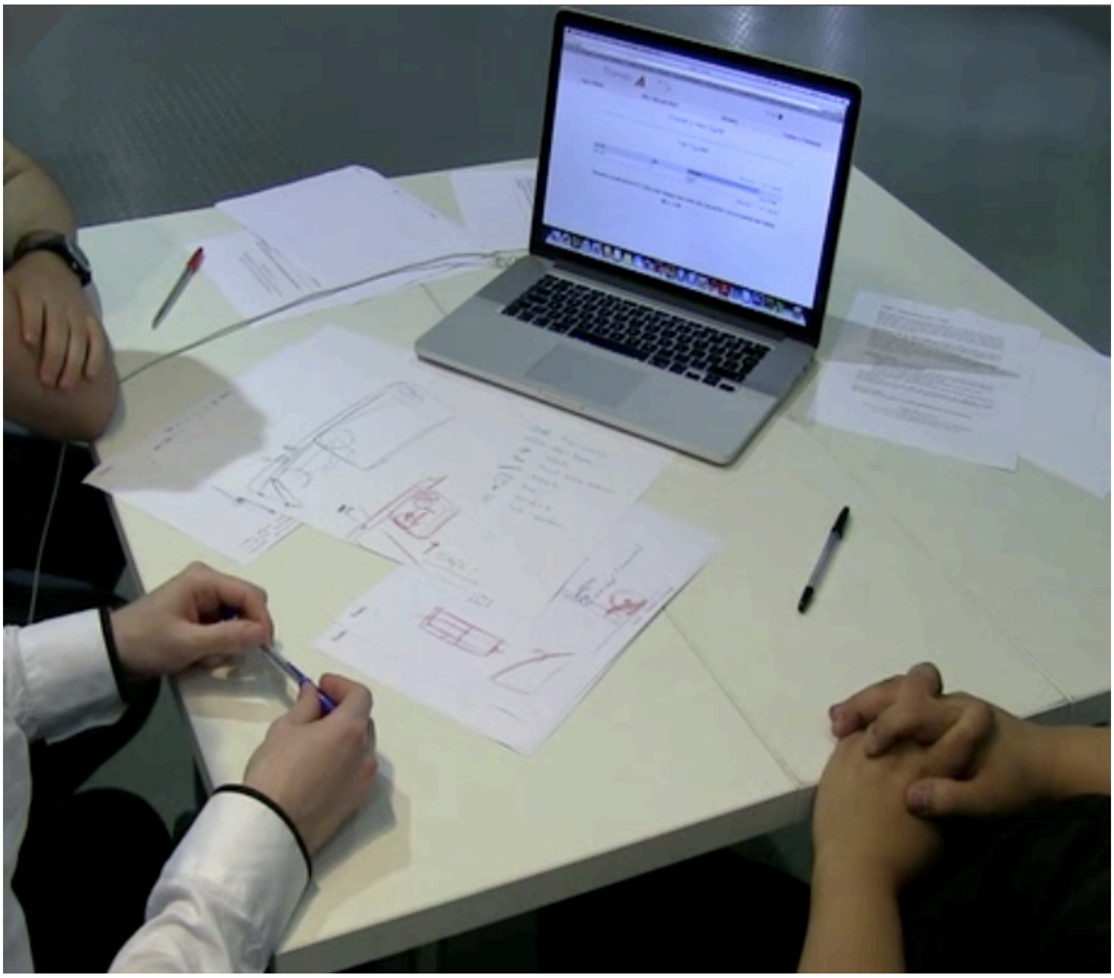


Fig. 5.11 Sample of RCA 02 at work

The first reaction when opening the recycling step window was to read the first line ‘consumers’ and Blue said: ‘oh, consumers? A lot’ and then opened the glossary information. After reading it he was still confused, and they did not understood if they had to input a number of consumers or material. Red was also confused and they agreed to input total number of consumers in the life span, for which they decided was five per day which they proceeded to multiply it by ten years. For producers and distributors they simply said ‘no’, and for compost Blue said that it could be composted, and then wondered what ‘compost’ meant, and opened the glossary window. When closing it Blue said ‘oh yes, definitely’ and proceeded to open the glossary window of landfill, for which Blue said that did not applied. It was not until they finished the step, closed the window and an error message popped up, that they realised they were required to input the percentage of product going to be recycled. They finally decided 97% for consumers, and 1% each for producers, distributors and compost.

They later discussed the business model step. Red explained the concept clearly and Blue opened several glossary information windows. They struggled to understand and define which was the appropriate one, finally selecting one randomly.

Second phase, refinement

The participants proceed with further exploration of the same idea. Some details such as accessibility and functionality were discussed, and the first sketches of this process continued in working sheet 02, on which the box mid way between far and close was crossed.

Discussing some security issues once the bicycle is on the post, Black recalled the idea of using electricity. Blue used working sheet 03 to explore this, and he ideates a battery pack fitted inside the frame tube, which will produce a small electric shock if anyone touches it. The idea is not pursued. In working sheet 03 the 'close' box was crossed.

Attention returns for a moment to the sketch in working sheet 02, and when feeling more secure about the solutions ideated, Blue takes working sheet 04 and redraws the same idea, this time to define the concept. A diagram of the mechanism, and a list of components are created. In working sheet 04 the 'close' box was crossed.

Trophec's second exploration

The exploration began by opening the PDF report of the cycle created earlier. On, seeing the full star they consider that their product was 'good'. One more relevant comment was made when checking the energy generation sources, and realising the use of coal and gas in Britain, Blue's reaction was of surprise and concern. They spend almost half the time analysing the data they inputted and the countries' characteristics.

Blue then proposed to go back to the previous cycle and add to it. They first added thermoplastic and aluminium in the materials step, both from Great Britain. They did this while discussing and making references to the components' sketches made earlier.

They look at the screen for several seconds without making comments, and Red proposes to 'play around and see what happens', while pointing to the recycling step. Blue agrees, and Red says 'we do it with four distributions', Red changes the final setting of 94% for consumers, 4% to distributors, 1% for each producers and compost.

After 30 seconds of watching the PDF report again, Red proposes that they 'add something like the worst case?' He attempts to add one more manufacturing process, but he only selects a country, not the process, so nothing is added. Not realising this he proceeds to open the PDF report, and when looking at the impact figures he states: 'its not changing much'. Even when he scrolls down and sees that they still have the same two processes as before, neither he nor his colleagues realise the mistake.

Third phase, definition

They decide to directly draw the final sheet and merge all the particular solutions into one. All three members participate on this, a list of components is first made and later two perspectives, one of the full object, and one detail. Lastly some text explaining and expanding on the proposals is produced. This task was performed in less time than was available, and so the participants decided to end the test sooner.

Interview

The researcher first asked them their impressions of the test and Trophec. Red commented that he felt more guidance was needed, giving the origin of materials as an example where it would be useful to know where they come from, and also where could it be cheaper in a comparative way. Blue said that he found it very important to have a faster and easier way to show which direction to take or how efficient something could be, but he was confused because the results were not clear enough. For him, the difference was not so evident when the production was changed from China to the UK. He connected this idea to his experience, saying that sometimes manufacturing far away could seem cheaper, but waiting times and possible errors and corrections makes it cost more at the end, and he proposed that it could also be included.

The researcher next asked if it made sense to have all that information at the early stages of design, when they were just making sketches, Blue replied yes, and he made an analogy: 'is like being in a candy store, too many things you don't know where to start, but you just try this and that, it could be overwhelming sometimes'. Red added that it is easier if you know where production takes places, but if not, there is a process of trial and error, repeating the idea of having comparisons, where it was cheaper or more expensive.

There was a balance between Red and Blue participation, nevertheless Blue dominated slightly more. This is believed to be because Red stated his background as a graphic designer, disqualifying himself from some decisions and work.

The total time of the test was 72:15 minutes, and including the interview 77:32 minutes.

RCA 03

In this set there were two non-native English speakers and one British citizen. Only one, Black had a very weak language skill, and his low participation in the session is believed to be because of it. This set did not fill up the ‘far – close’ concurrent report in any of their working sheets. Red reported to have two years of professional experience and Blue one year.

The test had the exact same protocol as RCA 02, with only the request being added to explicitly explain in as much detail as possible how the product would end its useful life.

Phase one, conceptualisation

This set started by reading the brief and reflecting if the solution should be something ‘mobile’ or not. Next, if it should be carried on the bike or in a backpack, later they move onto discussing materials and how bicycles are locked, one wheel, both wheels, the frame, etc. Red mentions that the front wheel is easy to take off, not so much with the rear because of the gears.

Then they searched in Internet in Wikipedia the ‘U’ lock. While doing this, Blue takes the working sheet 01 and draws a bicycle’s profile. With the argument of the front wheel being easily removed, they discuss the first concept of a front wheel immobiliser, attaching the front wheel to the frame or to an external element. After minute five they return to the Internet - this time to do image search in Google. They find a pedal that locks the bike, Red commenting that it saves space and weight. There is a short discussion about some determining variables, such as whether there is a fence or not to which the bike can be chained.

It is from this last discussion that Red proposes one more concept - the chain in the handlebar. This prompts a vivid exchange of arguments and ideas between Red and Blue and other concepts come about: remove bike part, chain in wheel’s hub, remove handlebar, collapsing wheel and make bike unusable; they run out of space and use working sheet 02.

Trophec’s first exploration

In materials they first choose steel. Blue mentions that it is a very subjective decision because they need to know how expensive the solution has to be, and proposes to be £20 pounds, again questioning if it is an add-on product or if it is built-in the bike. Red proposes his idea of a collapsible wheel, and Blue undertakes to do the cycle for that product. When selecting the material's country of origin, Blue says that if they want it cheaper, they should choose Africa or Asia, finally they chose Great Britain and comment 'it's premium'.

They next decide to add rubber for the tyre, which does not exist in Trophec separately, as it belongs to the thermoset branch. When searching for it Blue asks 'what is a thermoplastic?' Blue proposes to use bioplastics and requests Red to open its glossary information. They decide not to use it because of Blue's argument of being exposed to the sun and rain, finally they chose thermoplastic with Brazil as origin.

In manufacturing processes, first they chose forming with mechanical light intensity and Brazil as manufacturing site. Next they chose joining and cutting with mechanical medium intensity, arguing for a moment which process should go first.

For transport they chose ship as a logical option from Brazil to Great Britain. They engage in a discussion about the probable size, they are thinking in a wheel so they use their hands to reflect how big it should be, figure 6.12.

In usage they quickly decide 10 years as life span, and daily use. No petrol or electricity.

When entering recycling they ask themselves who will get this after consumers? Blue argues that compostable materials could have been used; but the life span then would have to be lower. Finally they select producers with 75% and without verbalised reflection or discussion, 25% to landfill.

For the business model they request help from the researcher, and after a brief explanation they select one quickly because the time for this phase was over. They briefly open the infographics section of Trophec.

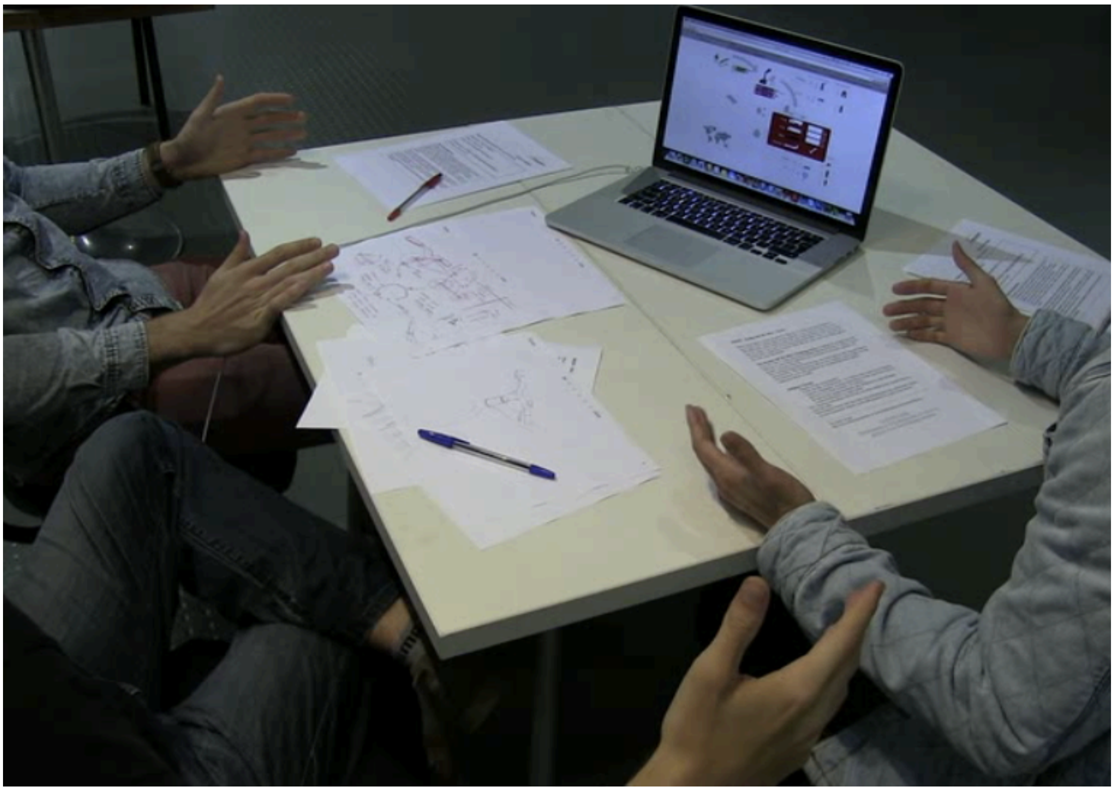


Fig. 5.12 Sample of RCA 03 at work, participants are ‘measuring with their hands’ to define packaging size

Second phase, refinement

The first comment was quickly made by Red proposing to explore the removable handlebar, Blue accepts it and in the following discussion they merge it with the concept of making the bicycle unusable. After a series of fast explorative sketches, Blue draws a larger version of the whole concept, meanwhile Red reads in the Internet about a collapsible wheel project. Shortly after, the process turns into defining the details of the solution, producing a large number of sketches and in a vivid discussion and exchange, Black’s intervention was only with sporadic comments. This process was registered in working sheet 03 and 04, with some interventions in previous sketches.

Trophec’s second exploration

Blue acknowledges that this time the cycle should be more complex since they have a more defined object, therefore they start a new cycle.

For materials this time they start with aluminium, and Brazil as origin with no apparent reason. Next is thermoplastics and later steel, both from India, decided by Blue, with no discussion. When deciding the amount for each material, Blue makes reference to the weight of a bicycle as a reference point.

Manufacturing starts with forming with mechanical medium intensity. Red proposes India as a manufacturing country, to which they all agree. The next step is assembly with hand medium intensity. Blue then says that they need one more forming process, mechanical light ‘because is a very small part’. Finally, one more process for the entire product assembly is proposed, also by hand because ‘that’s special’, states Red.

Ship is again chosen as the transport means, and they again used their hands to come up with the packaging measures.

In usage they input 15 years of lifespan and 5000 uses, with USA as selling destiny, no petrol or electricity is needed.

This time recycling with producers amounts to 95% of the product, after a reflection about the aluminium and steel being highly recyclable. Blue proposes that some of it can remain with the consumers; Red sets 2% for them and 3% to landfill.

Third phase, definition

Red starts writing in working sheet 05 the lifecycle of their product, starting from manufacture, followed by the user, between them there is a relation of ‘repair’ and ‘reuse’. When the bicycle ends its useful life it is mostly recycled to producers (steel and aluminium), and all the rubber goes to landfill. Together with this, there is a dialogue between Red and Blue, which concludes that they can ‘set everything’ for the product to be repaired and disassembled.

They continue to define some last technical issues, using Google images at around minute 63 to search for bicycle forks. In minute 70:30 Red states that they need to make the final board and gives Blue the A3 sheet. He starts creating a final drawing of the concept, in which Red collaborates. Almost at the end Black intervenes by also drawing some details.

Interview

The researcher first asked them their impressions of the test and Trophec. Red commented that for him there was a need for information about materials more specific for his working area, but for the test the program gave them a lot of information and that ‘that is an Index I wanted to see’. Blue mentioned that the colour coding helped him, it was fast and that it was very good for estimation. Black added that it helped him to identify the things they had to consider about the design.

This set was balanced between Blue and Red, with a very dynamic interaction and collaboration between them.

The total time of the test was 72:50 minutes, and including the interview 74:05 minutes.

5.9. - ONLINE DATA

Since its publication online in September 2012, Trophec was open to use for free to anyone in the world. Chapter three section 3.6 p.129 described all the activities to promote its use, and the successes of this promotion. Beyond the use of the tool in the previously mentioned sessions, the opportunity to gather data from hundreds of users provided a unique opportunity to acquire knowledge regarding designer's preferences and choices, in an environment such as Trophec.

The tool, operated by its users, recorded all activity independently. The researcher focused only on the promotion of the tool, in order to obtain the largest data set possible. It was then decided to download all data recorded up to the 12th of January 2014, due to the need to process it and include it in this document. All the downloaded information was divided in two different types: all cycles produced by all users, which are analysed as aggregated data in order to identify possible preferences and characteristics; and by users with more than one cycle produced, analysed individually, in order to identify possible patterns in their choices, which could lead to further insights for this research project. Further detail on this can be found in the following chapter.

5.10. - CONCLUSIONS

The investigative step of this research was a very challenging process; the author's almost null previous experience in performing these type of tests, and the continuous learning from the literature review, resulted in a series of unnecessarily ambitious goals, in novice assumptions and the subsequent improvements in the protocol, which have been described in this chapter and were a powerful source of apprenticeship.

This process gave as a result a clear understanding about what methods and under which conditions the identification of influence can be attributed to the tool. Interestingly it also raised unexpected phenomena that opened possibilities for future research. Verbalisations where the main source of evidence for the effects the tool had in their working process, and directly related is the need for short pauses and reflection, as well as straying from the belief that in order to improve a product's sustainability this needs to be well defined. While analysing the data an apparent pattern emerged regarding the approach to solve the design challenge and the type of professional practice the designers had. These two points will be elaborated in detail in the next chapter of this document.

Chapter 6 – DATA ANALYSIS AND INITIAL FINDINGS

6.1. - INTRODUCTION

The approach taken for data analysis, due to the amount and multiple types of sources, was through the production of charts and graphs. This allows for the visualisation and identification of patterns, events or phenomena, signalling any type of influence caused by the use of Trophec and a regular behaviour in its absence.

The previously mentioned uncertainty about how this influence may take place, led the author to think of different possibilities. As discovered in the literature review, there can be a correlation between the complexity/ambiguity and density of sketches with the stage of the design process. Normally quick, abstract and ambiguous sketches can be found in early stages of design, and as the process moves forward towards definition, sketches can become more detailed, containing more accurate information and explicit forms and functions. Another possibility was related to the progress of such design phases, even though it is well know that the design process is not linear, a progression towards definition and communicating the idea could be expected. Related to the last two is the ideation of concepts and their vertical and lateral transformations, chapter 2 section 2.7 p.95 (Goel 1995). It is expected that more lateral transformations are seen at early stages with a tendency towards vertical transformations at the end, clearly signalling the fixing of one idea and developing the details only.

Other aspects were explored, including the amount and time taken to create the sketches, as well as the collaboration between participants in the case of sets. It was anticipated that there would be a greater number and shorter time of creation at early stages, longer time and fewer sketches towards the end of the process. A further aspect was dialogue. The recorded think aloud protocol allowed the identification of the amount and length of verbalisations or periods of silence, as well as, if considered necessary, the undertaking of a more detailed analysis by coding the transcriptions with one of the mentioned coding methods.

The challenge lay in creating a visualisation method that allowed for the identification of these processes and possible correlations between them. In chapter three, section 3.5 p.109, some examples were given regarding how other researchers have visualised the process. The details of what they showed were discussed as well as, in relation to the needs of this research, the characteristics to improve or add.

This chapter will present not only the data analysis and the phenomena detected, but also the development and refinement of the visualisation method itself. Just as each test informed the necessary modifications to the protocol, they were part of that development and refinement too. The process will be presented in chronological order, and as mentioned previously, the pilot study and the test performed in Mexico will not be analysed for the aforementioned reasons.

6.2. - NORTHUMBRIA TEST: RELYING ON DESIGNER'S PERSONAL SKILLS, AWARENESS AND INTEREST

FIRST FLOW CHART DESIGN

Taking inspiration from other researchers' methods (chapter 3 section 3.5 p.109), it was decided to create a chart showing the chronological flow of events - the goal being to have all the data sources visually displayed accordingly to their time and sequence of creation. Therefore, the first task was to identify each individual sketch in its chronological sequence of creation, using the researchers' log (all having been previously instructed in its use). The sketches were then digitised and separated individually and saved in chronological order. Due to the amount of information, and in order to achieve a good readability, a document was created in Adobe Illustrator of 1350 mm width by 420 mm height (horizontal orientation), example in figure 6.1. The document was divided in two vertical sections; the first with 1000mm in width was dedicated to have the visualisation of the protocol, each 10 mm in width represented one minute of the test.

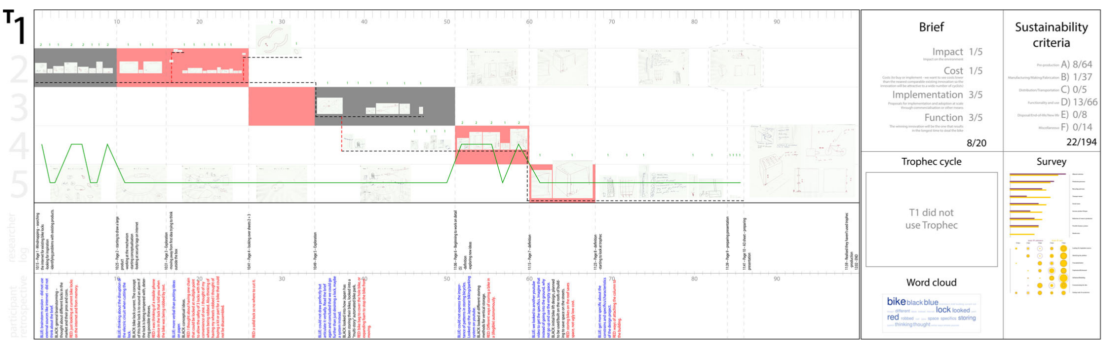


Fig. 6.1 First flow chart design

This section was further divided in seven rows, figure 6.2. From top to bottom, one to five represented the five possible answers of the concurrent report, one being 'far' and five 'close'. Row six was used to place the transcription of the researcher's comments accordingly to the time they were written. Row seven was for the retrospective report from participants. This was written after the test, so was placed in the flow chart accordingly to the working sheet from which they were extracted.

Fig. 6.2 Detail of division of seven rows

Each working sheet is represented by a rectangle with solid colour, the position depended on the statement of the concurrent report (one to five), and the size on the time length that working sheet was used. The colour of the rectangle represents which participant in the set marked that working sheet - each had a different colour pen (red, blue and black).

Once the working sheets were set, all the individual sketches were placed on top according to their sequence of creation and working sheet origin. By making use of the researcher’s log, the retrospective report and the sketch itself, the author identified the lateral and vertical transformations (Goel 1995), which were represented with a dotted line, red for the former and black for the latter, figure 6.3.

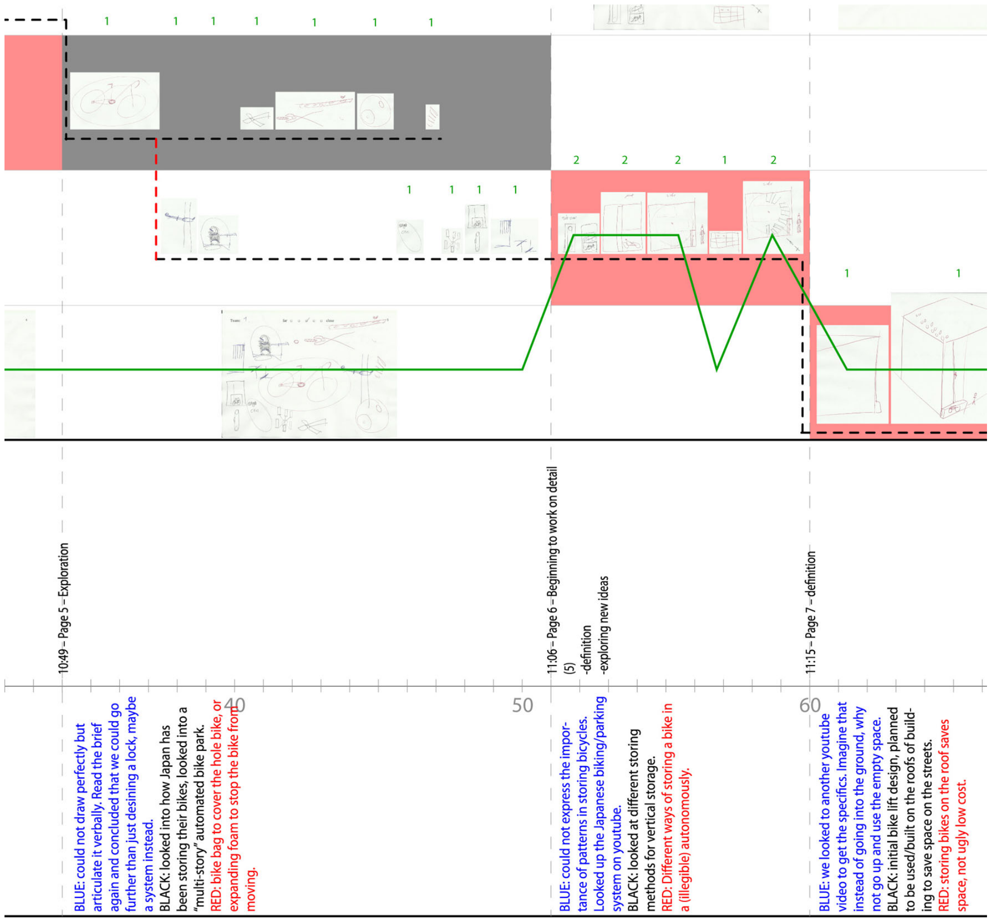


Fig. 6.3 Details of sketches, transformations and transcriptions.

Rows one to five were also used to identify each sketch's complexity scale (Rodgers, Green et al. 2000), (green line), this time row five represented complexity one, row four complexity two, row three complexity three, row two complexity four and row one complexity five.

In the case of video recorded groups the moments and duration of computer usage were also included. In the case of experimental groups this included the moment they used Trophec shown by placing its logo in the time line according to the moment they started using it.

The right side of the document was separated from the flow chart in order to include the brief grading according to NESTA's judging criteria, Figure 7.4 (NESTA 2013):

1. - Impact on the environment
2. - Costs to buy or implement
3. - Implementation and adoption at scale through commercialisation
4. - Functionality of product, length of time to steal the bike.

The researcher and an independent professional designer with 16 years of practice and academic experience, graded each final proposal following the Delphi Protocol, first individually and in secret, and five days later they graded again collectively, discussing differences and reaching common agreement.

This score graded with one point when no consideration was made in the final proposal, up to five points when it had been fully considered.

Sustainability criteria: each final proposal was reviewed by the researcher in order to identify how many of the 194 strategies of Fuad-Luke (2009) were included in the project. This was done by indentifying them in written statements or embodied in the developed solution. Furthermore, the results were plotted from the initial and final survey, a Word Cloud made from participant's written retrospective analysis, and in the case of experimental groups, the Trophec cycle, figure 6.4 and 6.5. Overall this data did not produce any significant evidence, no pattern nor any particular phenomena.

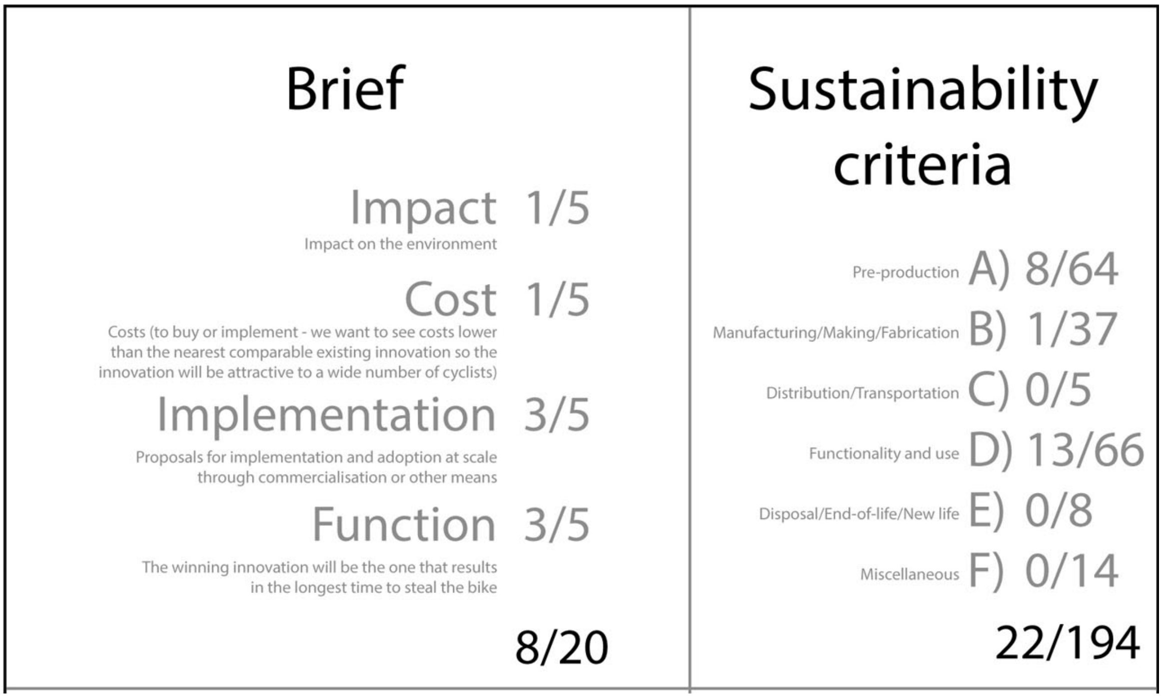


Fig. 6.4 Detail of the grading

Fig. 6.5 Detail of the grading

INITIAL AND FINAL SURVEY

For each team a graphic showing the differences between initial and final survey was developed, for each individual question and aggregating all sets' participant contributions.

The first question requested the definition of which of nine options they would consider when designing a new product. The second question related to the working time allocation in the design process.

Figure 6.6 and 6.7 show each group's aggregated results for question one and two respectively. Table 6.1 indicates how many groups decreased, increased or remained with the same opinion, for each option of both questions from the initial to the final survey. In the first line of each box the main trend is stated (up, down or equal) and the number of teams that chose that option. The second line shows the other results. Similar trends are highlighted in yellow and identical ones in green. The survey results were highly random, and did not produce any relevant evidence, nor could any particular phenomena be identified.

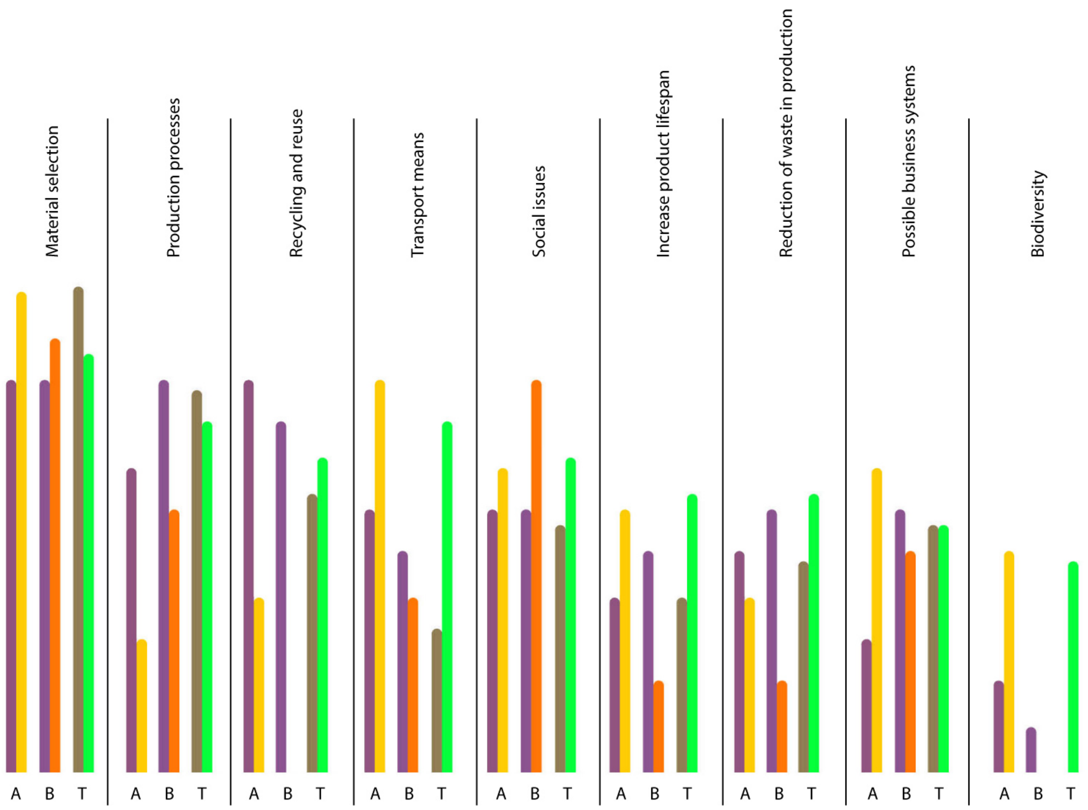


Fig. 6.6 Survey question one. Left line indicates initial and right final survey

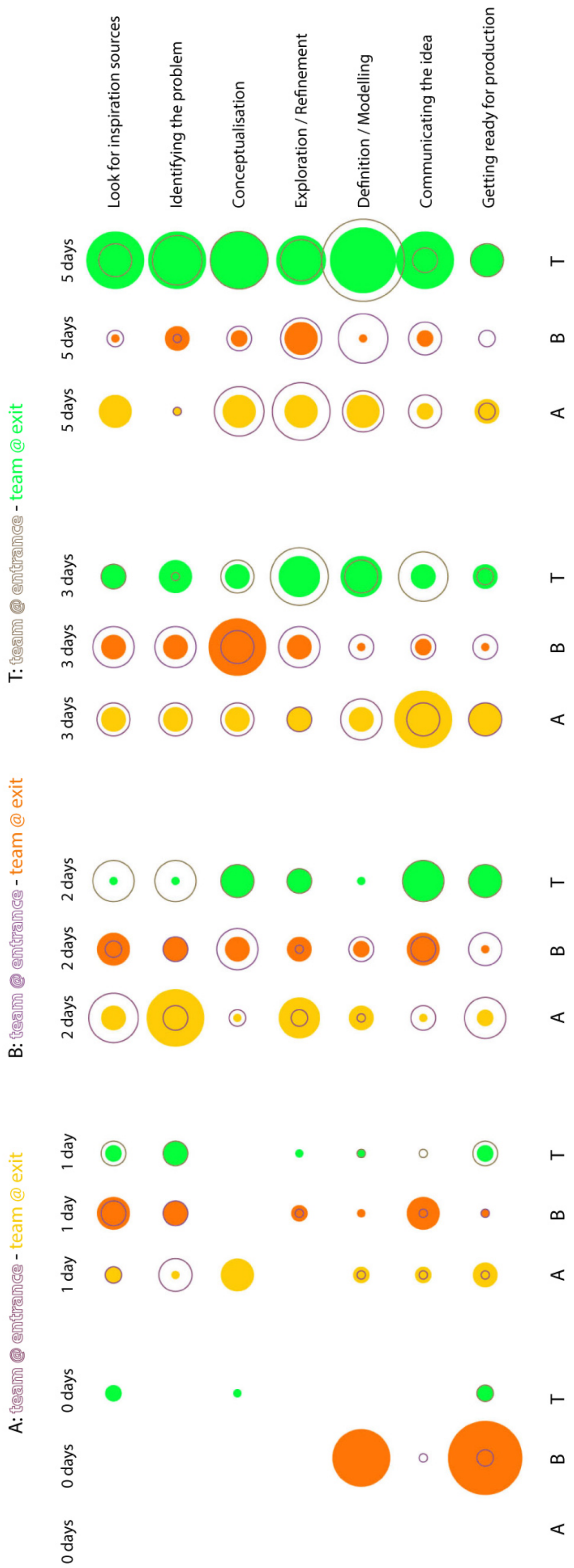


Fig. 6.7 Survey question two, hollow circle indicates initial and full circle final survey, the diameter the number of participants selecting that option

	Material selection	Production processes	Recycling and reuse	Transport means	Social issues	Increase product lifespan	Reduction of waste in production	Possible business systems	Biodiversity
B	↑2 ↓1 =1	↓3 ↑1	↓3 ↑1	↑2 ↓1 =1	↑2 ↓1 =1	↓3 ↑1	↓3 =1	↓2 ↑1 =1	↓1 =3
A	↑3 =1	↓3 ↑1	↓4	↑3 ↓1	↑2 =2	=3 ↑1	=2 ↑1↓1	↑3 =1	↑2 ↓1 =1
T	=3 ↓2	=2↓2 ↑1	=4 ↑1	↑5	=3 ↑2	=3 ↑2	=3 ↑2	=3 ↑1↓1	↑3 =2

	Looking for inspiration sources	Identifying the problem	Conceptualisation	Exploration / Refinement	Definition / Modelling	Communicating the idea	Getting ready for production
B	↑2 ↓2	↑2 ↓1 =1	=2 ↑1↓1	↓3 ↑1	↓4	↓3 ↑1	↓4
A	↑3 ↓1	=2 ↑1↓1	↓3 ↑1	↓3 =1	↓3 =1	↓2 ↑1 =1	↑2 ↓1 =1
T	↓3 ↑2	↑3 ↓1 =1	↓3 ↑2	=3 ↑1↓1	↓2 =2 ↑1	↑4 ↓1	↑3 ↓1 =1

Table 6.1 Increments or decreases in each group. Yellow indicates the similar trend, green the exact same respond.

GRADING: BRIEF AND SUSTAINABILITY CRITERIA

In order to compare groups' performance, the results of all sets were plotted together in two different tables, one for the brief judging criteria (table 6.2) and the other for the sustainability criteria (table 6.3). Groups are arranged progressively according to their identification number, from left to right. In the tables can be seen how the students' main focus was on functionality and overall no relevant differences between control and experimental groups are discerned.

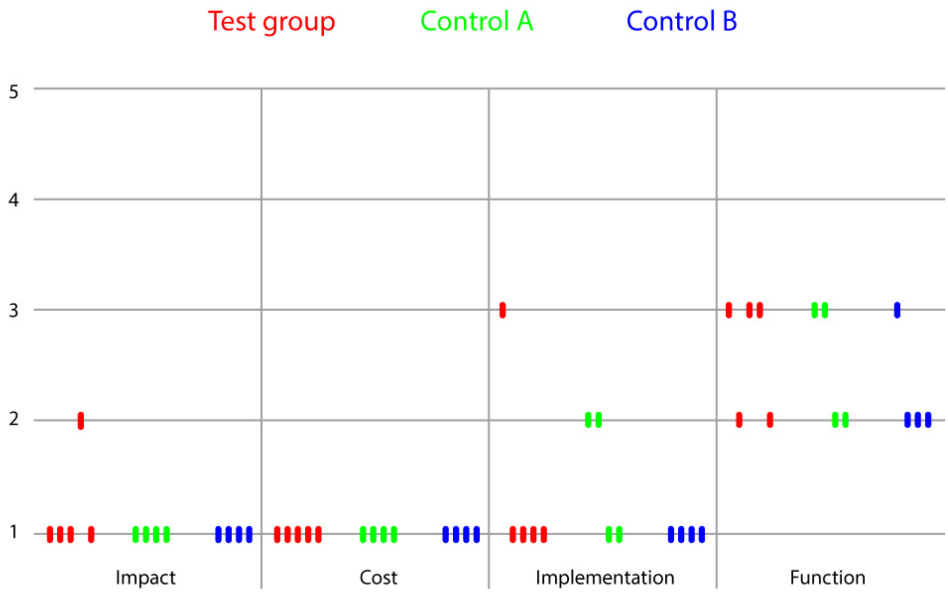


Table 6.2 Brief judging criteria for all groups, One = not considered, five = fully considered

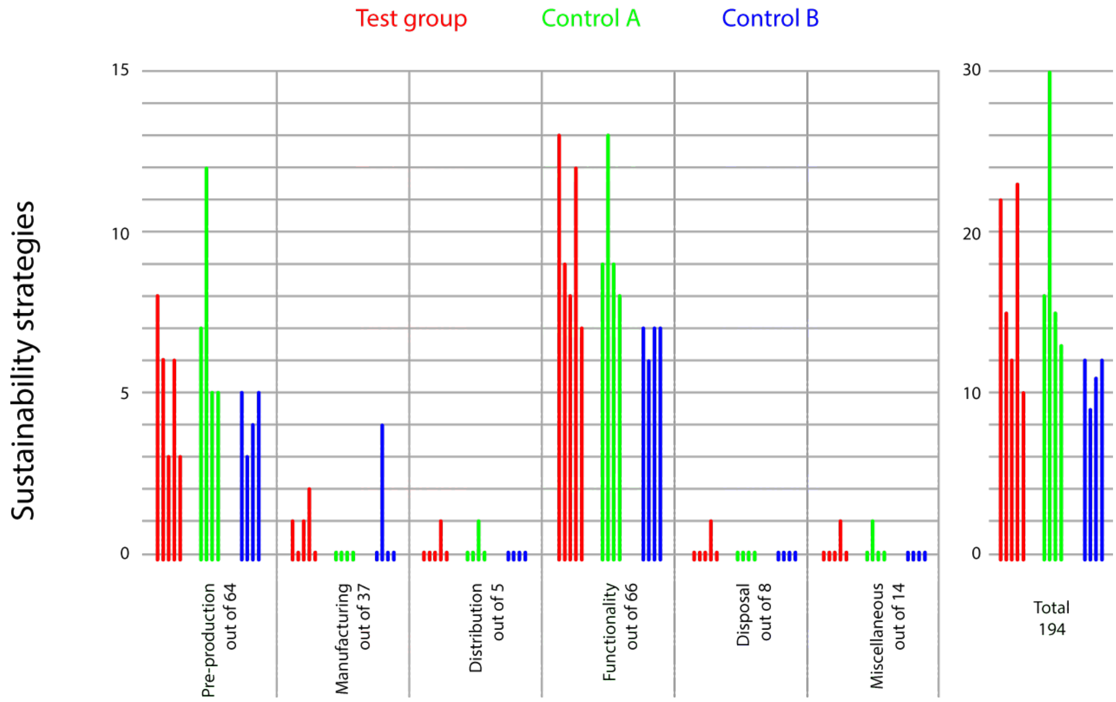


Table 6.3 Sustainability criteria for all groups. Number of strategies per category in final proposals

SKETCH AND TRANSFORMATION ANALYSIS

For all groups, the lateral and vertical transformations and the sketch complexity scale graphics were isolated, examples of the three sets can be seen in fig. 6.8. The dotted line represents transformations; black are 'vertical' and red 'lateral' (Goel 1995). It is very important to note that in these charts 'vertical' and 'lateral' are not related to a Cartesian spatial meaning, but to a temporal one, and should therefore be read according to the time line, from left to right. The green line represents sketch complexity; level one being the bottom of the chart and top level five. The green line is in some cases interrupted because there were no sketches made at that point. In some cases only written notes were made, which are not represented here. At the top of each flow chart the time scale in minutes can be seen, read from left to right. Although there are important differences in these results, they produced no discernible pattern that indicated an influence from the tool; these differences are believed to be simple personal approaches for problem solving, which can also be related to group dynamics.

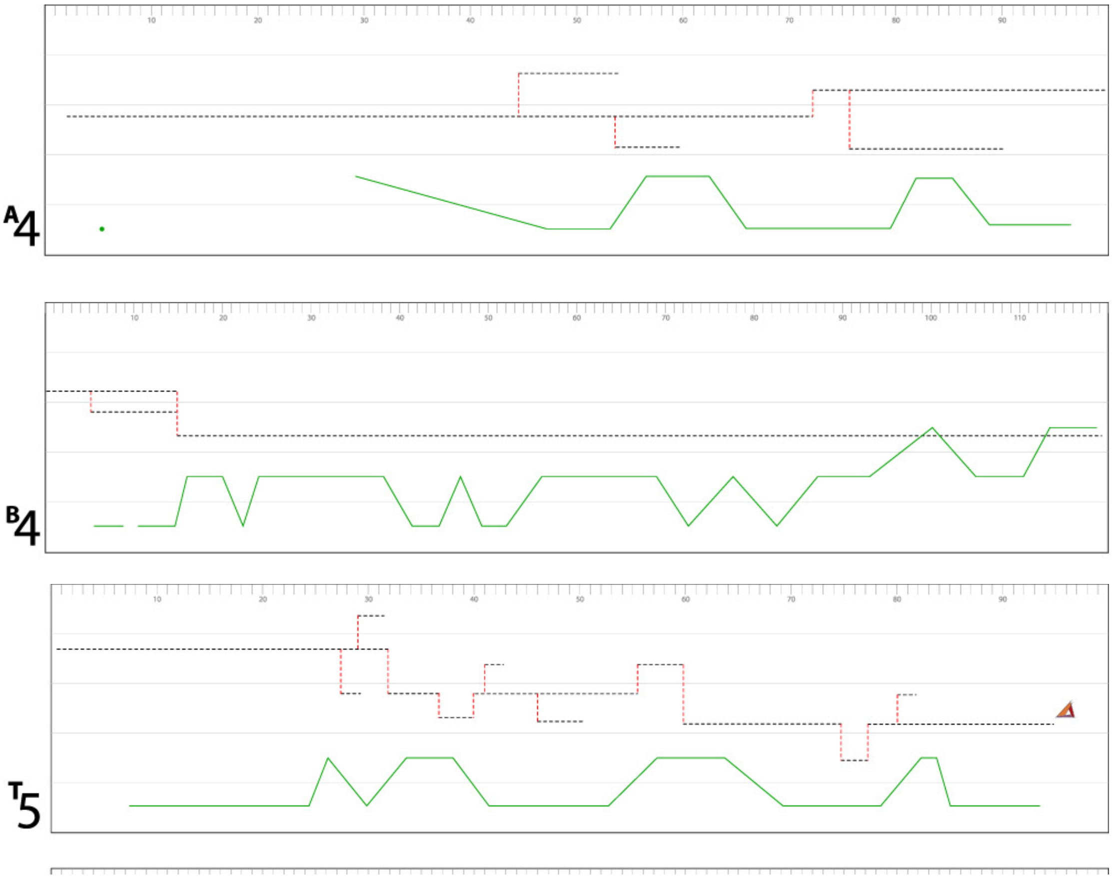


Fig. 6.8 Example of sketches' transformations and complexity set A,B and T at the bottom, which includes the moment Trophec was used (triangular icon).

Word clouds

In order to gain further insight from the experiment, a Word Cloud[3] was created from each group's retrospective report, which every participant made by writing on the back of the working sheets (fig. 6.9). In the Word Cloud the size of the word represents the number of times the word was repeated. In this analysis only the words found two times or more were included. The researcher inputted the words 'black', 'red' or 'blue' each time the participant made a comment; in this way it can also be understood which participants were more or less active. By crosschecking this information with the concurrent report and sketches' colour, a picture can be gained of whether it was a collaborative process

[3] A visual representation of the occurrence of text data in a source, it can be highlighted by colour, size or a combination of both.

between group members or a whether certain predominance was imposed. This data source produced no particular pattern that indicated influence by the use of the tool or any other discernible phenomena.

A word counting in all groups was created and each set's total average.

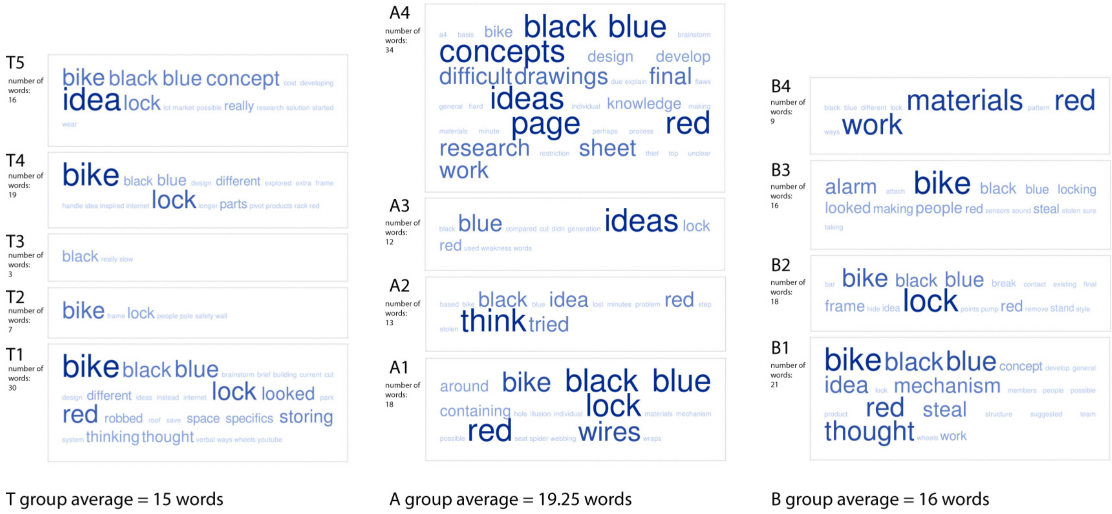


Fig. 6.9 All sets' word count and each group's average

CONCURRENT REPORT

All sets were asked to fill one of the five options of the scale in the working sheets, indicating 'far' (one) or 'close' (five) in relation to 'how they felt they were at that point from the final solution'. The differences between groups clearly indicate the ones producing good workflow or the ones who experienced a poor progress. The use of the coloured pen also enabled indications of whether it was a collaborative exercise or not. The table also shows the amount of working sheets used (table 6.4). Although the results are different, these differences are believed to be related to group dynamics and personal approach to problem solving. It did not produce any evidence on the influence or otherwise of the tool.

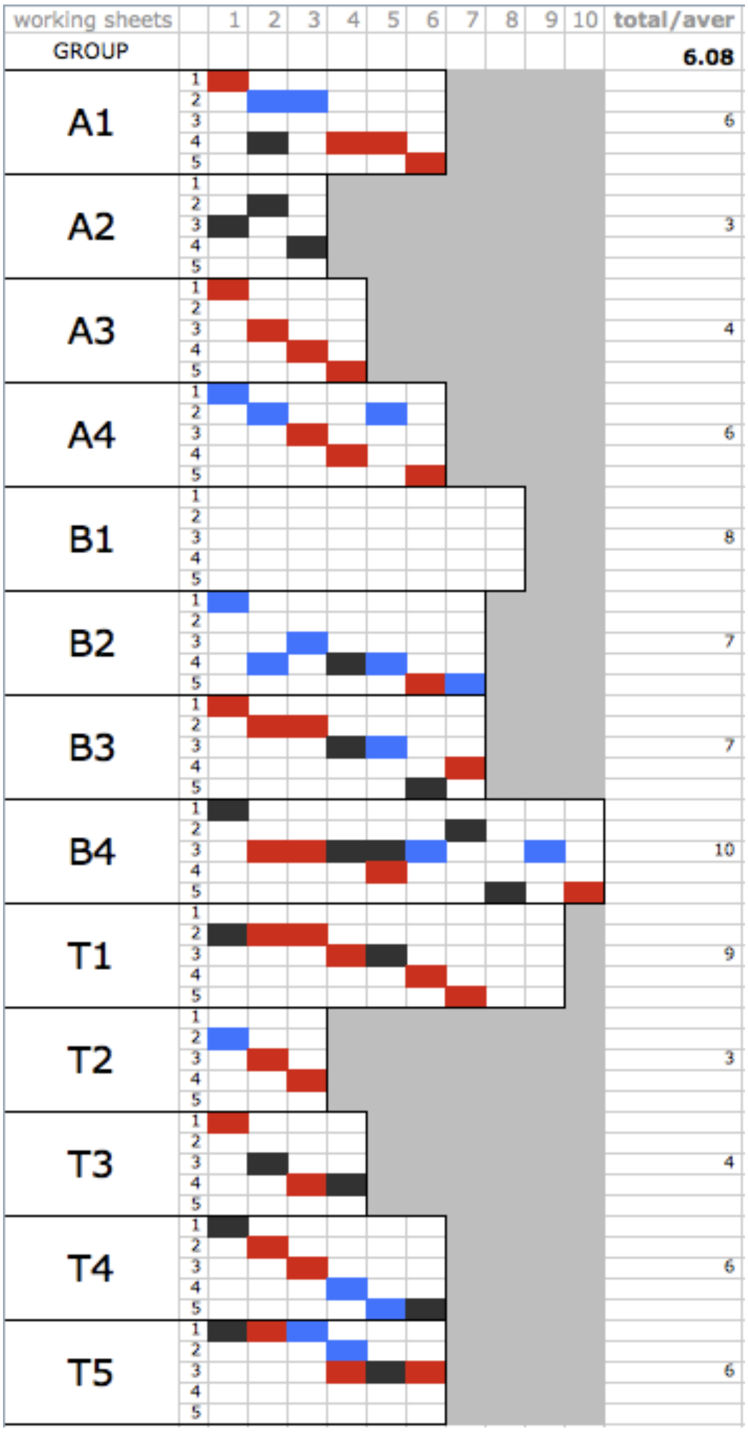


Table 6.4 Concurrent report all groups

RETROSPECTIVE REPORT

All groups were asked, at the end of the test, to write on the back of each working sheet what they were doing or thinking at that particular time. Later it was all transcribed and incorporated into the flow charts. This information complemented the identification of lateral or vertical transformations, as well as the detection of conflicts, difficulties, complains, etc. Nevertheless, did not produce any evidence regarding the influence of the tool in the designers' working processes.

GUIDE TO IDENTIFY A 'RAW STRUCTURE' OF DESIGN PROCESSES

After reviewing the retrospective reports, a pattern started to emerge and particular word combinations were found. Based on the work by Günter et al. (1996), in which they in order to identify a 'raw structure' of the design process (in this case meaning a simplified method to speed up the process when there is no time or need to perform a detailed analysis with a coding method), proposed a guide to identify three particular phases:

Phase 1 – 'Clarification of the task. The aim of this phase is to understand the task and to get information about the requirements'.

Phase 2 – 'Searching for concepts. This phase consists of the search for different principal solutions for the sub functions of the design problem, the judgment and selection of these solutions, and their combination in order to achieve a concept for the design problem'.

Phase 3 – 'Fixing the concept. This phase includes the further development of the concept to an optimum in accordance with the technical and economic criteria (e.g. costs, ergonomics, forces and stress). It leads to a status where embodiment design in a layout drawing can begin. The result of fixing the concept in our experiment is a hand-sketched preliminary layout' (Günther, Frankenberger et al. 1996).

The identified key words and/or phrases from the retrospective report allocated accordingly to the proposed design process step:

1. - Looking for Inspiration Sources

 'Same problem', 'existing', 'previous concept', 'researching already available', 'market', 'current designs', 'internet', 'youtube', 'google'

2. - Identifying the Problem

 'What', 'how', 'why', 'reason', 'weaknesses', 'flaws', 'necessity'

3. - Conceptualisation

 'Though concept/idea', 'explore concept/idea', 'novel concept/idea', 'figured out', 'possible idea', 'several concepts/ideas', 'generation'

4. - Exploration / Refinement

 'Develop-suggest-find', 'similar structure', 'developed idea', 'thought exact shape/about mechanism', 'early versions', 'compared ideas'

5. - Definition / Modelling

 'Work exactly', 'working system', 'thought system', 'structure product'

6. - Communicating the Idea

 'Finalising concept/idea', 'final drawing', 'story board', 'last minute', 'final idea'

7. - Getting Ready for Production

 None

From this set of words and phrases, a short description of the identification of a 'raw design phases structure' used in this analysis is described next.

Looking for inspiration sources: Reviewing printed or online material, recalling one's own or other people's experiences related to identical or similar problems, and how they were solved. Searching for existing solutions, products already available in the market or design proposals by other designers that maybe have not reached production. Common sources used, because of their speed and accessibility, are Google searches (images or web) and YouTube.

Identifying the problem: Understanding and reflecting on the task, and getting information about the usage requirements. Usually involves questions emphasising actions like 'what is actually happening?', 'how it happened?', 'why it happened or didn't happened?', looking for reasons, weaknesses, flaws and 'real' needs, etc.

Conceptualisation: Ideation of solutions and their combinations in order to achieve an initial concept for the design problem. It may incur in rapid analysis about advantages or problems of such ideas, it may involve statements emphasising actions like 'I thought of… concept/idea', 'explore… concept/idea', 'novel… concept/idea', 'figured out', 'possible idea', 'idea/concept generation', etc.

Exploration: The task of deeper analysis of a single concept, incursion into possible structures, mechanisms, materials, shapes; production of early versions to compare variations of a single concept. It may be used to also compare, mix, and judge different concepts, it may involve statements emphasising actions like: 'developed idea', 'develop-suggest-find', and 'thought about shape/mechanism', 'it could work', it would never work', etc.

Definition: Final development of a single concept with detailed definition about technical, ergonomic, costs, etc. factors. Fixing solutions, which may emphasise actions in statements, like 'works exactly', 'working system', 'structure', etc.

Communicating the idea: The production of all material to be shown to others who were not involved in the development. The objective of these materials is to explain and sell the final concept; it may involve final drawings, presentations, videos, models, etc.

Getting ready for production: The production of all the technical information to start production, specification of materials, assembly, providers, etc. Normally in form of blueprints, highly detailed CAD models, check lists, written documents, guidelines, etc.

With the latter descriptions, a graphic representation was created to attempt to visually communicate in what part of the process they were at on each working sheet, examples of the three set can be seen in fig. 6.10.

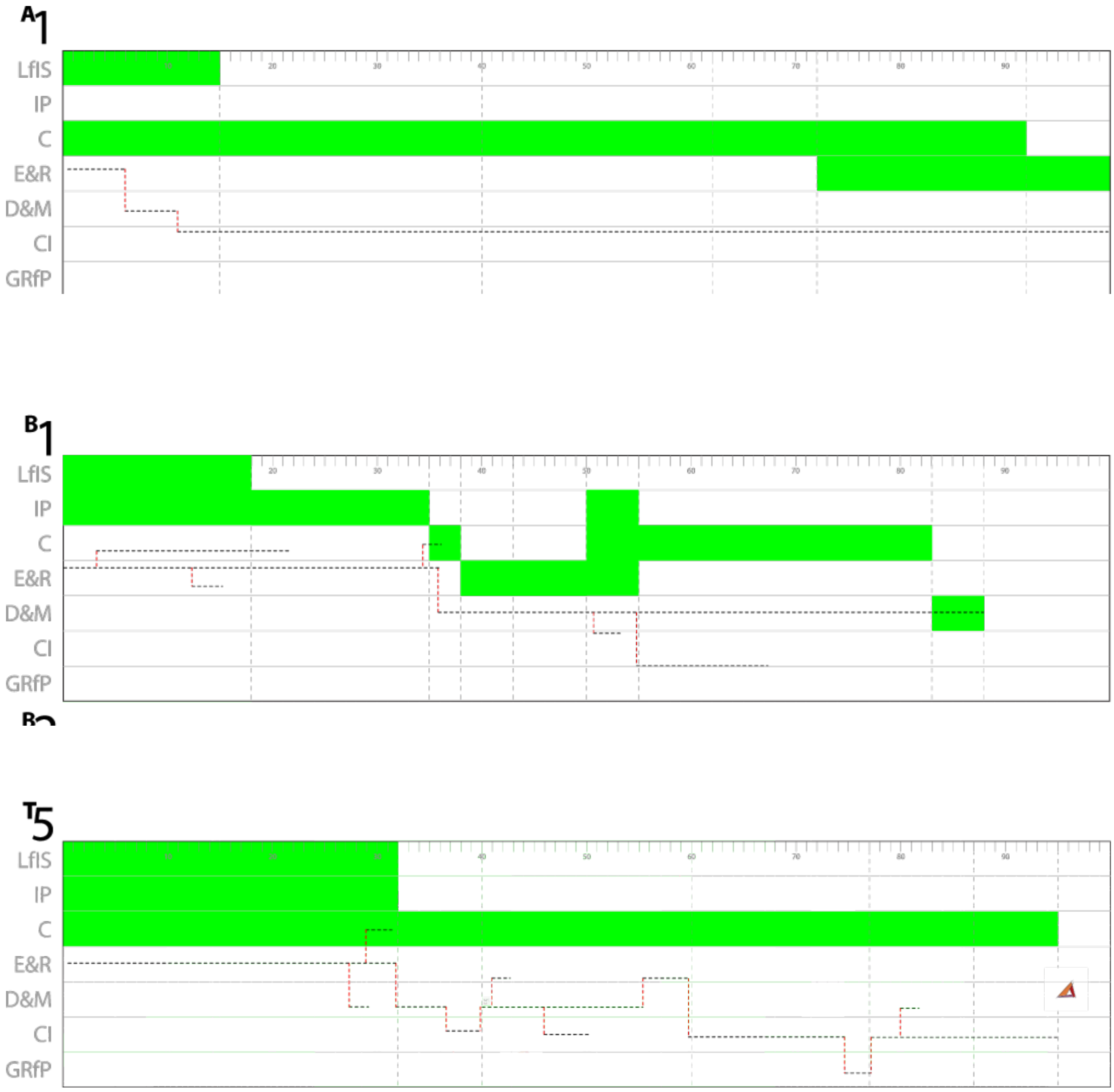


Fig. 6.10 Example of design process derived from the retrospective report, group A, B and T, which includes the moment Trophec was used (triangular icon)

6.3. - NORTHUMBRIA TEST SUMMARY

The first essential matter to point out is that there are no general significant differences between control sets and the experimental set. Secondly, there is the issue of the low quality of all proposals. The highest group in brief criteria obtained only 8 points out of 20 possible. In terms of the sustainability criteria, the results in general were very poor, raising questions about the quality of sustainable design education. Moreover, grading with the 196 strategies from Fuad-Luke (2009), proved to be highly subjective and confusing, mainly due to the fact that many of these strategies are very open and in some cases seemingly redundant or overlapping. A more objective strategy could have been asking independent researchers to grade it, but the labour intensive and time consuming exercise made this an unviable option. Thirdly, all groups concentrated almost exclusively on the functionality aspect of the brief.

Nevertheless, two phenomena can be directly related to the presence of Trophec. T3 had some packaging and size considerations and these can clearly be seen in the sketches, the sketch complexity and the retrospective report. However, they seem not to have provoked any reconsideration of the final design. When assessing packaging, some of the expected changes might be in the overall size of the product, number of pieces or material type, in order to decrease the weight. It is thought that none of this took place, probably because of lack of time.

Similarly T4 did some materials and manufacturing processes considerations and these can clearly be seen in the sketches, the sketch complexity and the retrospective report. However, they did not represent any reconsideration of the final design, probably because of lack of time, due to the fact that Trophec was used almost at the end of the test, and once the final design was defined.

One last analysis was made by identifying the best four groups graded in both brief criteria and usage of sustainability strategies. These groups were: T1, T4, A1 and A2. They all present certain similarities:

The number of lateral transformations is low, no more than 3 and early in the process. Also all of them reached the “Exploration / Refinement” step of the design process and also lack of incursion in the “Identifying the Problem” step. Nevertheless only 5 out 13 groups entered this step (41%).

Finally the proposals can be grouped in three categories:

1. Urban (parking spaces, integrates a social dimension)
2. Built in (a lock included in the bike, no need to buy extra item)
3. Add on (classic extra object to buy)

The first two can be considered more sustainable than the third one according to (Vezzoli and Manzini 2008), in this regard group T1 and A2 created an “urban” solution and T4 and A1 a “built in” solution. All other groups proposed an “add on” with three exceptions: A4 proposed a “built in” solution, this group showed several lateral transformations all the way to the end of the test, a probable sign of a lack of consensus. T2 proposed an “urban” solution, just like A4, it had many lateral transformations very late in the process. And B2 a “built in” solution, this group presented an average amount of work and an apparently fluid process; nevertheless it was the worst graded in sustainability as well as brief criteria.

The lack of difference between control and experimental sets may well suggest that designers' different awareness, skills and interest regarding sustainability matters may be a differentiator, which supports the argument made in chapters six and seven about the relevance of better understanding this issue and eventually overcoming it. It became evident as well that the single fact of presenting the software, and knowing in advanced that the test was related to sustainability, or even that the brief was explicitly requesting sustainability considerations, was not enough to encourage students to produce sustainable solutions, even less to use the tool in support of their design process, which supports the authors found in literature review chapter 2 section 2.5 p.43.

The strongest and most revealing evidence of this is the use of Trophec at the very end, when the final concept was already chosen and being developed. This phenomena is consistent with what has been discussed previously, namely the practice of investigating sustainability requirements only at the end when is precisely less efficient to do so. Furthermore, the only group in the experimental set that produced a 'systemic innovation' (Brezet and van Hemel 1997), T1, did not make use of Trophec at all.

All these preliminary results suggest that applying a tool such as Trophec early in the design process, while designers are just generating ideas, might not be appropriate if not considering short pauses in the process that permit reflection. It seems necessary too to overcome the apparent habitude of engaging with sustainable design once the product has been designed. This lead to the idea of changes in the protocol for subsequent tests, where steps of the design process could be included, and time for those iterations and reflections allowed. Doing so in a way that the tool and the information that delivers could represent multiple meanings and values.

6.4. - ROYAL COLLEGE OF ART, DESIGN PHASES AND REFLECTION ON GRADUATE STUDENTS

Three sets of three students participated in this test. For the first set a recreation was attempted of the conditions of Northumbria's test, in which no steps of the design process were introduced and no indication given as to when to use Trophec. This set (RCA1) is considered as the 'control group'. RCA2 and RCA3 had the same protocol (three design phases and Trophec used after phase one and two), with the only difference that RCA3 was explicitly requested to explain what would happened with the product at the end of its useful life.

FLOW CHART DESIGN CHANGES

All subsequent tests were made with a video camera capturing the participants' voice, hands and computer, which gave a highly detailed look at the entire process. The researcher reviewed each video several times, and identified the chronological order of sketch creation. Therefore, several changes were made to the design of the flow chart: firstly there was no 'researcher's report', and the participant's retrospective report was substituted by the actual transcription of the participant's dialogue. It was also decided not to include the images of the sketches, mainly to reduce the size of the chart to a more manageable A3. One more important change was the vertical set of the flow chart, to eliminate confusion about the correlation of 'lateral' and 'vertical' transformations, with the Cartesian spatial notion of the reader. Other changes and additions were made; the new contents and their description are detailed next:

1. In vertical, the duration of the test in minutes can be found in left and right borders, the test was designed to last 80 minutes.
2. First column (from the left), labelled with the participant's code (fig 6.11). The sessions were video recorded and all verbalisations transcribed. In this column the transcription is placed according to the segmentation and duration of each statement (statement segmentation was based in pauses in verbalisations, a minimum of 0.2 seconds separated one statement from the next one). Each individual participating is displayed in different colour, in the case of professional designers, black is the participant and red the researcher. In the case of students (three members per team), each member has a different colour (red, blue and black) and the researcher is identified with green.
3. Second column 'P', the design session was divided in three phases (conceptualisation in yellow, refinement in orange and definition in red) each lasting 20 minutes (fig 6.11). Between phases one and two, and two and three, 10 minutes were allowed to use Trophec (in blue). This second column shows the duration of each phase according to the test design.
4. Third column 'Pr', the design session as it took place (fig 6.11). The most 'naturalistic' conditions were always attempted; therefore, sometimes the participants decided to finish earlier, to take more time for different phases or even eliminate phases, and this column shows those differences.
5. Fourth column with a computer icon, the moment and duration that participants used the computer for purposes other than Trophec (fig 6.11).
6. Columns five to ten, steps of the design process (Aspelund 2010) (fig 6.11):

    L: Looking for inspiration sources

    I: Identifying the problem

C: Conceptualisation

E: Exploration

D: Definition

C: Communicating the final idea

7. Column eleven with a drawing pencil icon, sketches creation (fig 6.11). With the video recorded session all sketches were identified chronologically and in three different types: green figural representations (Goldschmidt 1997), dark blue written notes independent of any figural representation, light blue, written notes complementing figural representations. It also identifies the time the sketch took to be created and the links between them (adding to a previous sketch). In the case of teams the links are of two kinds, red: linking sketches of the same participant, orange linking sketches from different participants.
8. Columns twelve to sixteen 'far ---- close', on top identifies five different 'states' declared by the participant in a concurrent report (Sternberg 2003) (fig 6.11). All participants had several working sheets, in each sheet participants were asked to complete a concurrent report each time a new working sheet was used, marking them on a scale of five boxes from far (left) and close (right). The request was to declare how far or close they felt to obtaining a final solution. In these columns the duration of each working sheet can be seen in grey blocks (solid or in lines), and how 'far or close' the participant felt at that time.
9. The same columns are used to identify the complexity of sketches; at the bottom of the flow chart a green sequence of numbers can be found (one to five). One corresponds to the lowest complexity and five to the maximum complexity (McGown, Green et al. 1998). For each figural representation from column eleven, a green dot would be found determining that sketch complexity, figure 6.12.
10. On top of columns twelve to sixteen (without any relation to them) is shown the moment when a concept was ideated, and their lateral and vertical transformations (Goel 1995), (if any) in dotted black lines. For each figural representation a green cross can be found on top of the vertical transformation indicating to which concept each figural representation belongs, figure 6.12.

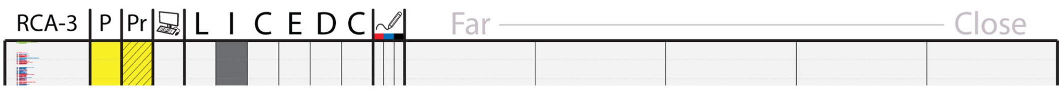


Fig 6.11 Details of columns header

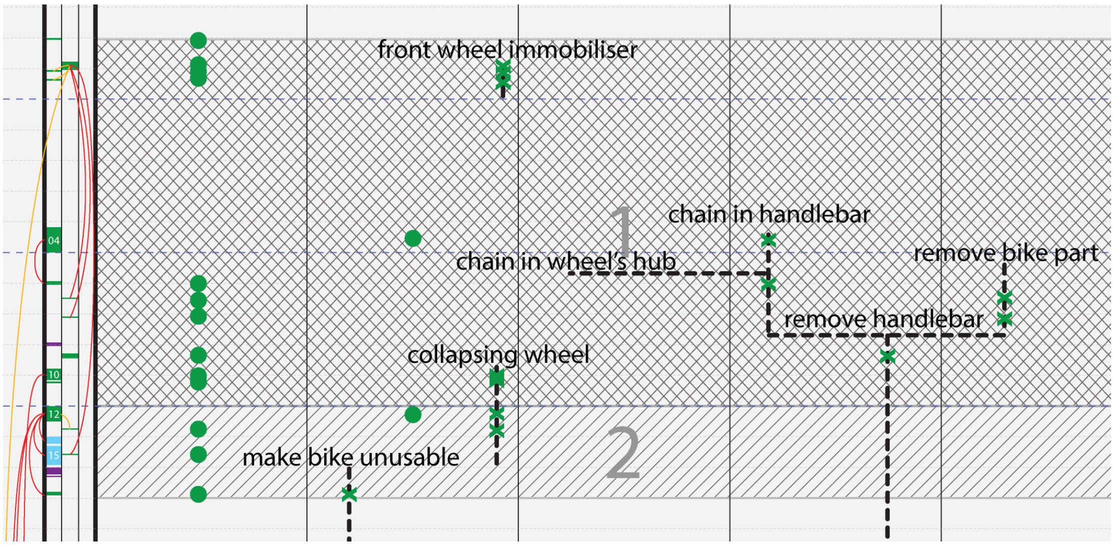


Fig 6.12 Details of sketch complexity, transformations and new concept generation.

SURVEY

The initial and final surveys were also applied, but as shown in Northumbria's test, the results were also very random and produced no significant information and are therefore not included in this document for this and subsequent tests. Nevertheless, the survey captured relevant information about the participants' profiles and opinions about sustainability. Almost all participants expressed a high interest in applying sustainability criteria in their practice, but reported a wide range on their ability or otherwise to do so, the reasons ranging from lack of knowledge, complexity of the task, no correlation between personal thinking and practice requirements, and some issues beyond the designer's capacity. Four out of nine reported having some sort of sustainable design training, table 6.5.

		training in S.D?		how interested in applying sustainability in your practice?					how easy you find applying sustainability in your practice?					main reasons?	Pro-exp
		Y	N	considerable	moderate	some	little	no	very	moderate	somehow	little	no		
RCA1	Blue		■			■							■	Gathering information and understanding what and how the source is capable, is very difficult to find.	-
	Red		■	■							■			Lack of knowledge of true environmental impact of processes, materials, etc. Knock-on-effects	0.5
	Black		■	■								■		There are lots of things outside design. i.e. manufacturing that has environmental impact, but we tend to neglect that aspect when designing with sustainability in mind.	-
RCA2	Blue	■		■								■		Extremely much research & interviews to do in the start: new technologies, materials, manufacturers, their possibilities to source energy sustainably & manufacture healthy, the whole transport of goods, materials as part of research, laws, cost factors, netwroks to build	2
	Red		■	■						■				To date I have not required to design for sustainability as I have worked as a graphic designer.	3.5
	Black	■			■								■	The main reason is connection between practice and my thinking. That there is always difficult.	2
RCA3	Blue	■		■						■				In professional work it's a lot harder whereas at university it is actually a main focus	1
	Red	■		■							■			Not knowing what materials are sustainable. Where to source materials from.	2
	Black		■			■						■		The concept of sustainability is (illegible) and not sure	-

Table 6.5 Initial survey responses

BRIEF GRADING

In order to grade RCA's and the professional designers' proposals according to the brief requirements and judging criteria, three experienced faculty members of the Design Department at Northumbria University were asked to mark individually all the final deliverables from all tests. This means they also graded the Northumbria's test, which will be discussed in section 6.8 p.264. The marking was done with the same parameters as before, with a scale from one to five, where one was 'not considered' and five 'fully considered'.

In the case of RCA1 (the only set which did not used Trophec, in orange in figure 6.13), the solution was an 'add on' product, a flexible and retractable chain, which if cut, would stain the bike and thief with indelible ink. The overall mark was 2.9, which puts them in second place from all three RCA sets, and the lowest of all in environmental considerations. RCA2 was the highest with an overall mark of 3.3, but only thanks to their high mark on 'function'; they are on top of all four categories. RCA3 was the lowest in the overall mark with 2.6, but surpassed RCA1 in environmental considerations. RCA2's solution was an 'urban' proposal: a parking device in street posts, and RCA3's a 'built in' solution: a collapsible handlebar functioning as padlock, which forces them to have a fence to which they can lock the bike, probable reason for their low score in 'function'. In figure 6.13 it can be seen how consistent all groups were in 'impact', 'cost' and 'implementation', as well as how much focus RCA1 and RCA2 placed on 'function' as they themselves expressed in the interviews.

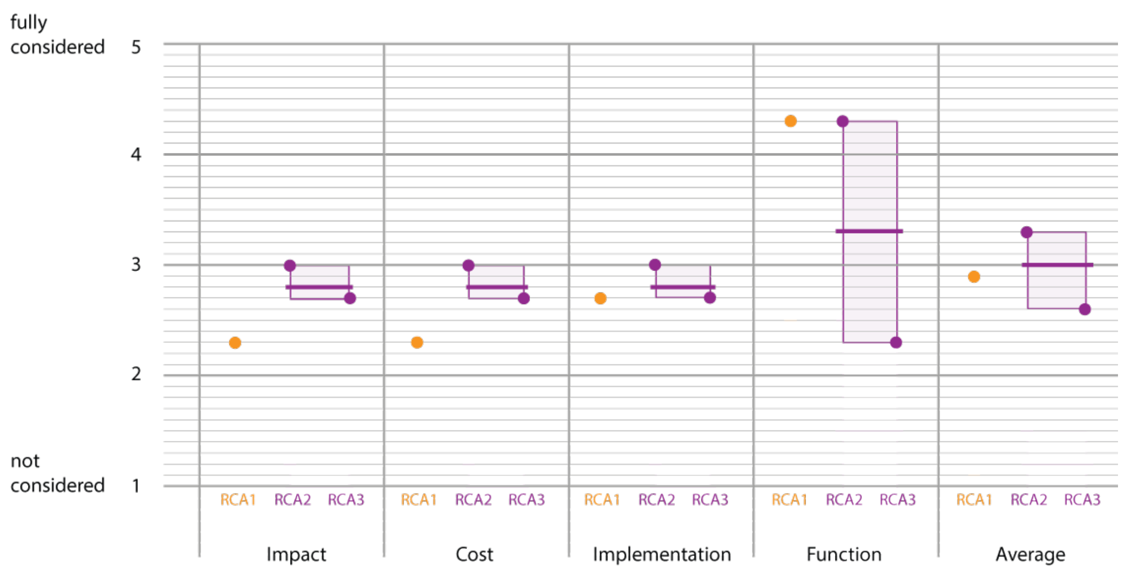


Fig. 6.13 RCA's Brief grading: Environmental impact, Cost, Implementation and Function

For this test and all subsequent tests, the sustainability grading made with Fuad-Luke's strategies was not used. As explained previously, the exercise was too subjective and confusing due to the broad characteristics of many of the strategies.

SKETCH AND TRANSFORMATION ANALYSIS

There is a noticeable difference between the structured and the non-structured processes (RCA1 on left, RCA2 in the middle and RCA3 on the right) figure 6.14.

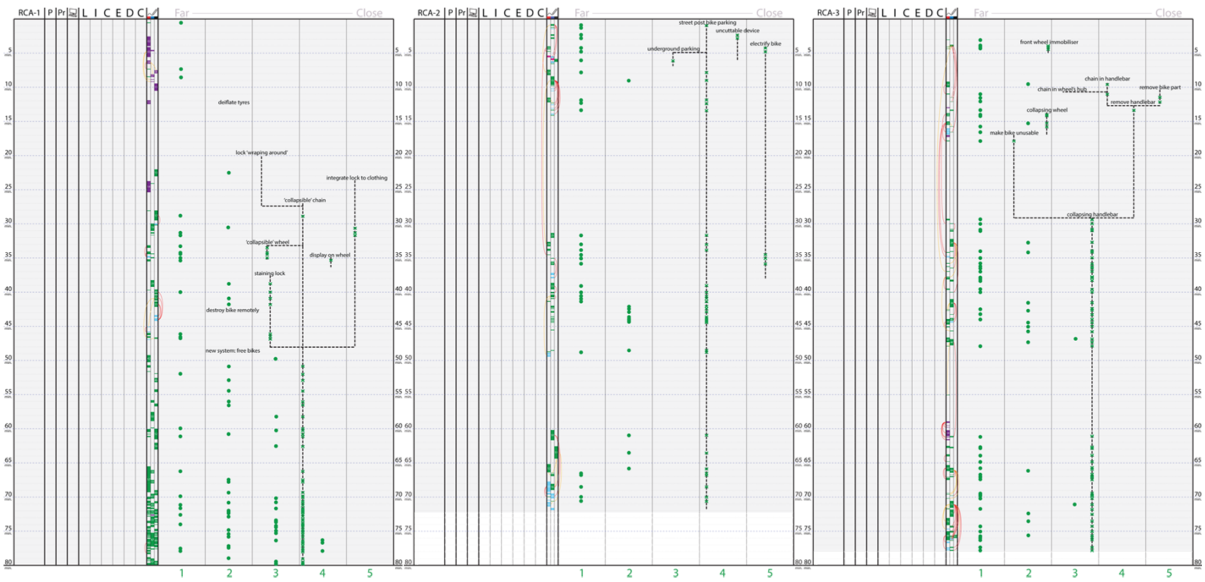


Fig. 6.14 Sketch and transformations, all RCA one, two and three sets

RCA1 had three very participative members; with the amount of sketches very balanced between all three. A difficult start made them create, in the first twenty minutes of the test, only mainly written notes, with the first concept accompanied with a figural sketch coming in the 28th minute. Nine concepts were created in total, five of them the product of lateral transformations, which finally led them to their final proposal. A highly important increase in the amount of sketches can be seen in the last fifteen minutes of the test. Moreover, the eighth working sheet was finished in the 76th minute, and the five extra sheets they used were in the last five minutes of the test. These were used mostly individually, to explore different solutions of the final concept, but it was clear that they ran out of time and could not arrive at a final agreement on which was their final sketch, despite achieving a high level of sketch complexity (level four). In general a progressively higher degree of sketch complexity can be seen towards the end of the test. A low degree of links between sketches is also noticeable.

RCA2 included one graphic designer (Red), who from the outset declared himself not to be expert on the theme, and therefore disqualifying himself from some decisions and proposals; and an overseas student (Black) who struggled with the language and hardly participated at all. These factors left the task of managing the test to Blue. The lack of disagreement or the proposal of alternative solutions led to the ideation of only four concepts, only one lateral transformation, and all ideas were created very early. The blue participant, with some interventions of Red, lead sketch creation. Nevertheless, there are more links than RCA1, which had a richer exchange of dialogue and ideas. The process is also mainly figural representations, with some notes explaining them. A slight increment in sketch complexity can be seen towards the end of the test.

RCA3 produced mainly figural representations, and ideated concepts as early as minute three. In the first seventeen minutes they had created seven new concepts with two lateral transformations. After Trophec's first exploration they laterally transformed two previous ideas into the final proposal, which was then developed exclusively. This set produced the highest amount of links between sketches, and a slight increase in sketch complexity can be seen towards the end of the session.

Although an interesting source of data, there is no strong or definitive evidence of influence of the tool during the process, all phenomena observed refers to group dynamics and personal approaches to problem solving, which are not the central point of this research project.

CONCURRENT REPORT

RCA1 used all eight working sheets and requested five extra sheets that were used in the last six minutes of the test, and which were not marked 'far-close'. For those sheets used a progressive sequence from 'far' to 'close' can be seen, the former reached at the seventh sheet. RCA2 was marked exclusively by Blue and a progress towards 'close' is clearly defined, which is reached in sheet three. RCA3 did not mark any of their sheets. In table 6.6 the moments in which Trophec explorations took place are shown with blue vertical lines.

Therefore, concurrent reports did not show any evidence of influence from the tool; any discernible pattern was either the expected phenomena or related to group dynamics and personal approach to problem solving.

working sheets		1	2	3	4	5	6	7	8	9	10	11	12	13	total/aver	stdev
GROUP															8.00	5.35
RCA 1	far															
															13	
	close															
RCA 2	far															
															5	
	close															
RCA 3	far															
															6	
	close															

Table 6.6 RCA's concurrent reports

VERBALISATIONS AND RETROSPECTIVE REPORT

In all three cases the dialogue was very intense, with lowest amount of verbalisations in RCA2. In the case of RCA1 the work progressed more slowly and only reached 'exploration'. For RCA2 and RCA3 they reached the 'communicating' step and even finished some minutes earlier, figure 6.15.

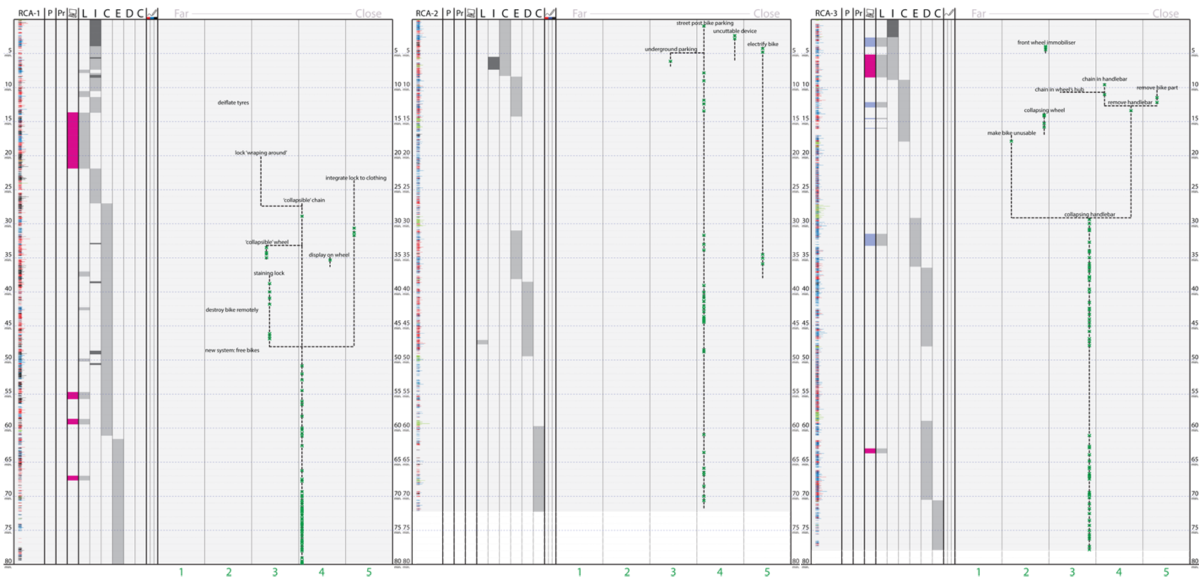


Fig. 6.15 RCA's transcriptions, design steps and transformations

In RCA1 the dialogue was very intense and in general balanced between all participants. This led to the identification of the design steps they were going through, a long identification of the problem step and looking for inspiration sources taking up the first 27 minutes of the test, followed by a long period of conceptualisation, where most of the ideas were produced. They returned several times to the brief as well as the computer, which was only used to see images in Google. The last 18 minutes of the test was about exploration. Once they agreed on the final concept, each participant took their own working sheet and drew their own interpretations. When they realised the allotted time was coming to an end, they attempted to react and come up with one unique design, but this could not be finished on time.

The dialogue in RCA2 was intense too, with some diminishing at the end. Because of the early agreement on the final idea, the process move forward quickly and reached the ‘exploration’ in minute eight. The same reason made them reach the ‘communication’ level. The entire process was sequential with progressive flow.

The dialogue was also intense in RCA3, but concentrated exclusively between Red and Blue. Black was an overseas student and struggled with the language, and his contributions were very limited throughout the entire test. Red and Blue produced a fluid and rich process, which allowed them to reach the ‘communicating’ step; the entire process can be seen as a normal progressive one. This set used the computer not only to look for images on Google, but also to directly search for similar projects in webpages they already knew.

TROPHEC

RCA1 did not use Trophec, even if introduced, following the same protocol as Northumbria’s test. They were introduced to the tool with the videos and allowed ten minutes for familiarisation, but they never thought about using it for their process. In the case of RCA2 and RCA3 the protocol requested the compulsory use of the tool, nevertheless the option of creating a cycle or simply navigate the glossary information was offered, they all chose to create cycles (fig. 6.16 and 6.17). A higher degree of complexity can be seen in the second exploration, mostly adding materials and manufacturing processes, and some changes in the other factors. These changes are consistent with the idea of increasing complexity and the ‘commitments’ made when moving forward into the design process.

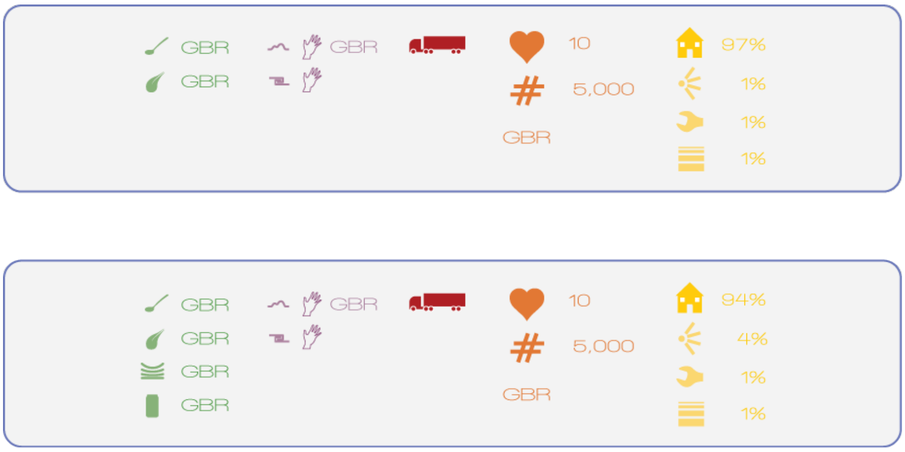


Fig. 6.16 RCA 2’s Trophec selections, top first exploration, bottom second exploration

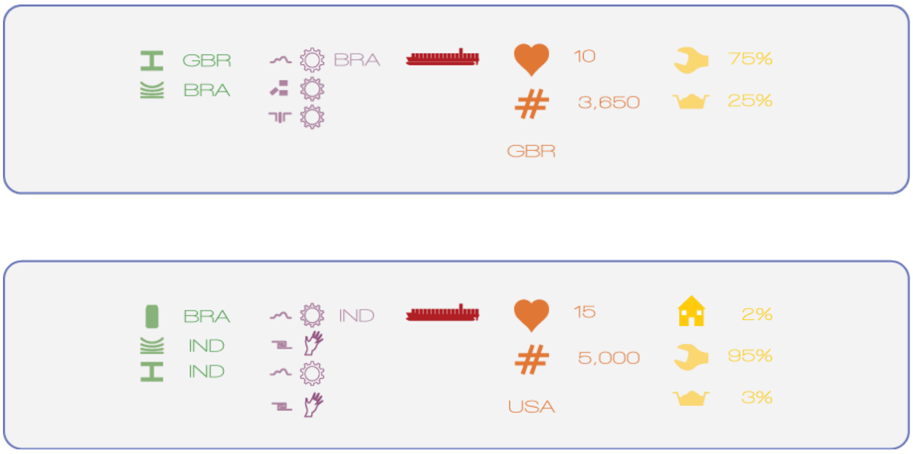


Fig. 6.17 RCA 3's Trophec selections, top first exploration, bottom second exploration

RCA2's first exploration with Trophec was an assessment of their concept. At this point they already had a clear idea of some of the materials to be used, and consideration was needed of other factors, like the number of times the product was going to be used or life span. But these reflections seemed not to provoke any changes in the original design, other than an increase in the detail and complexity, which is expected in a normal design process, and it is consistent with the second exploration, where more materials were added and some minor considerations on the recycling changed. This reaction may show that even when a design is defined, the inclusion of sustainability considerations is not guaranteed, and as discussed previously, a possible reason is the lack of demand from clients and therefore the suspected lax education in sustainable design. This phenomenon was stronger and with clearer evidence amongst professional designers, which will be presented in the next section of this chapter.

The first exploration of RCA3 is dedicated to assessing one of the concepts they had created, which did not end up as the final one. The second exploration changed completely, in which they focused on the final idea and selected, seemingly randomly, the countries where materials and production would be sourced. Nevertheless, as expected, a higher complexity can be seen in the second exploration with a higher number of materials, manufacturing processes and even recycling outputs, which again is consistent with the nature of the design process. Nevertheless, in working sheet five, Red drew an idea of the product's life cycle, which included factors like 'repair' and 'reuse'. These, together with some considerations verbalised about the need for 'disassemble', might be the product of reflections derived from the use of Trophec, the general requests of the test or their personal interest and knowledge in sustainable design, unfortunately there is no clear way of identifying the motivation.

INTERVIEWS

All tests finished with an unstructured interview. Overall, the comment was that sustainability is something to add later, once the concept is defined. In relation to the tool, the comment was made that it was fast and easy to understand and is highly relevant for conceptualisation stages. In some cases they requested even more simple and intuitive graphics, as well as larger material selection.

The reasons for RCA1 as to why Trophec was not used were as follows:

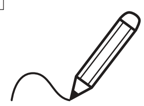
- Black: brief-focus.
- Red: focused on winning the contest! Sustainability as 'another layer' first the idea, then we go back in, I see it too far down the process rather than early on.
- Blue: I didn't know if Trophec results were real.
- Red: it didn't occur to me, I thought we were going to use it later.
- Black: once you set everything then you use it; first develop several concepts before we go to a more refined idea.
- Black: unless project is 100% about sustainability, then you have to focus on that.

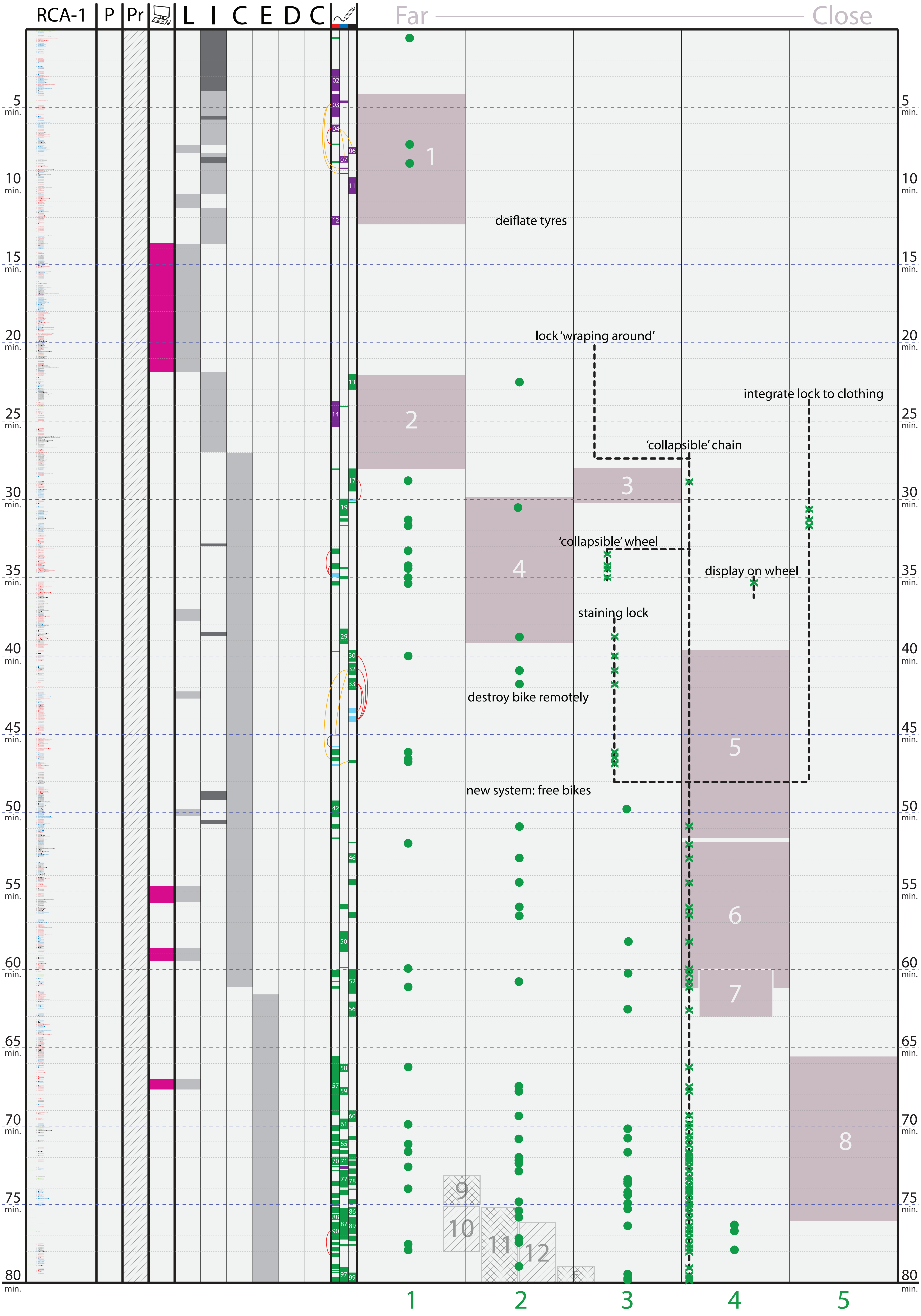
RCA2's comments were focused on the tool, with a need expressed for more guidance 'to know where to start'. They found the speed and simplicity to be a positive thing, but requested even further clarity. The idea of comparing between concepts and adding economic considerations was also raised.

Once more the need for a larger set of materials was raised as an issue by RCA3, and the speed and simplicity in the graphics highlighted as a positive, specifically the very useful colour coding.

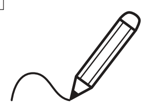
Therefore, from the interviews it can be deduced that there is a preconceived idea of when and for what a tool for sustainability should be used, which makes the introduction of a tool such as Trophec more complex. At the same time clear indications of the appropriateness of certain characteristics of the tool as well as some necessary changes and potential improvements were also identified.

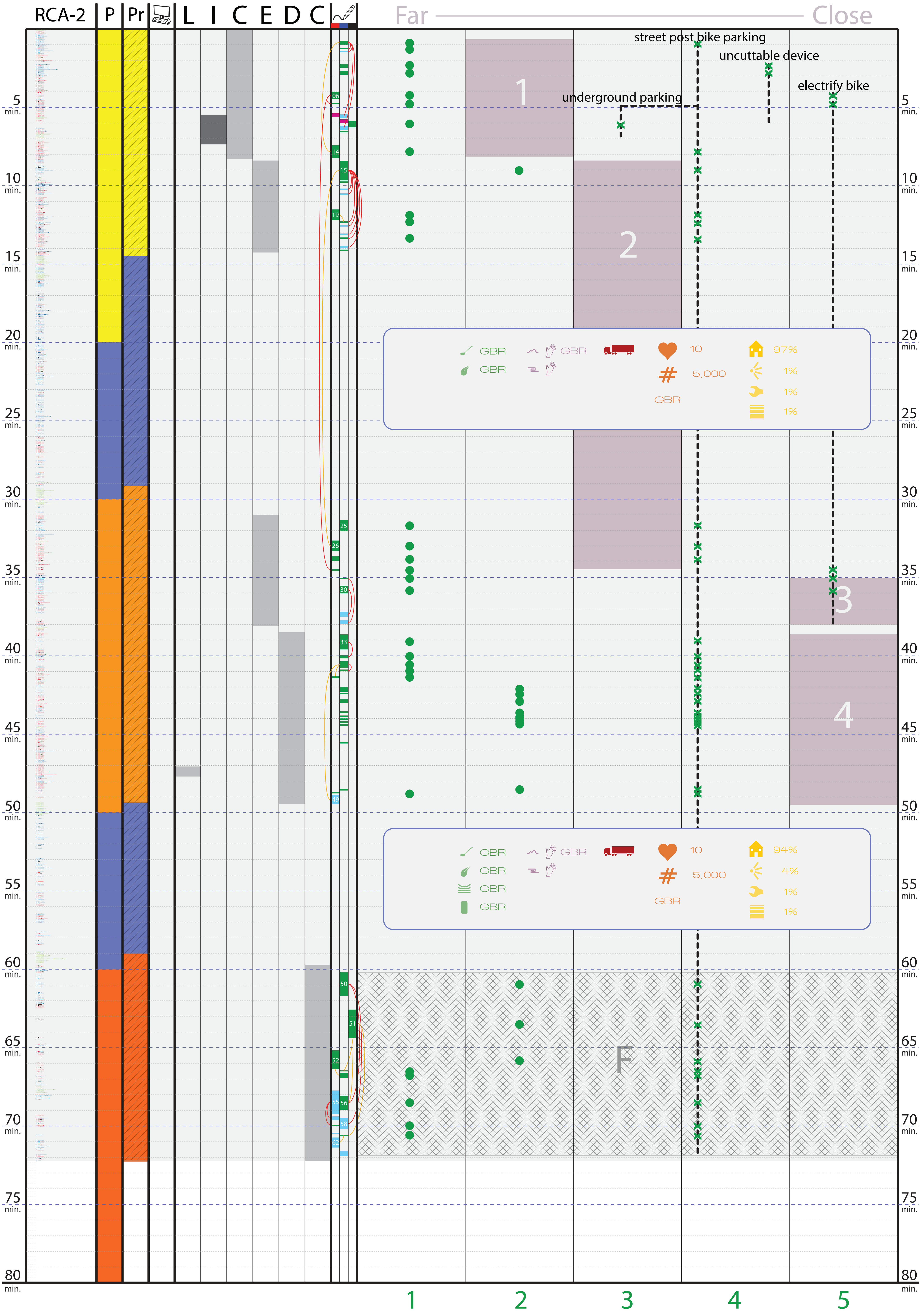
The full charts in A3 size for all RCA sets can be found in the next pages.

ITEM	Description	Column
	Transcription 'Black' participant	PRO-00 or RCA-00 (Participants' code name)
	Transcription 'Red' participant	
	Transcription 'Blue' participant	
	Transcription Researcher	
	Protocol phase 'Conceptualisation' as designed for protocol	P
	Protocol phase 'Refinement' as designed for protocol	
	Protocol phase 'Definition' as designed for protocol	
	Trophec explorations as designed for protocol	
	Protocol phase 'Conceptualisation' as it took place	Pr
	Protocol phase 'Refinement' as it took place	
	Protocol phase 'Definition' as it took place	
	Trophec explorations as it took place	
	Computer usage - Google images	
	Computer usage - Google web search	
	Computer usage - 3D modelling and render	
	Computer usage - Key note	
	Design process stage participants were working on	L - I - C - E - D - C
	Reading the design brief	
20	Figural representation and number of chronological creation	
	Figural representation's complexity degree (grading 1 to 5 on the bottom of page)	Far ---- Close
	Figural representation's relation to vertical transformations	
	Writing complementing figural representation	
	Writing general comments, reflections and ideas	
	Computer based board	
	Sketches' link, same designer	
	Sketches' link, between different designers	
	Vertical transformation	Far ---- Close
	Lateral transformation	
padlock	Concept ideated	
1	Far - Close concurrent report first answer and working sheet number	
	Far - Close concurrent report second answer (same sheet)	
	Far - Close concurrent report third answer (same sheet)	
	Far - Close concurrent report not answered, WS pairs	
	Far - Close concurrent report not answered, WS odds	

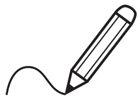


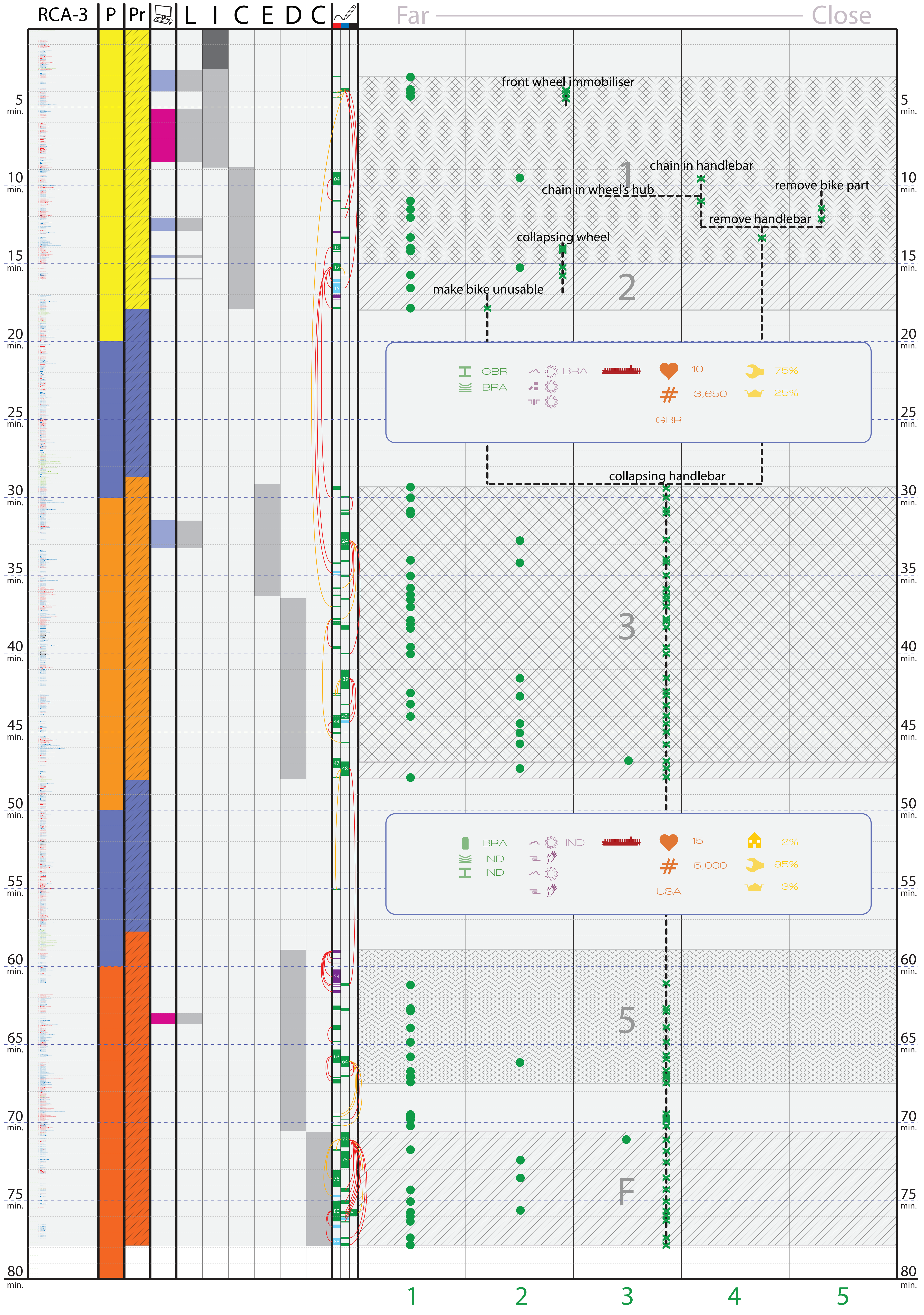
RCA-1
P
Pr
L
I
C
E
D
C
Far
Close
1
2
3
4
5
6
7
8
9
10
11
12
deiflate tyres
lock 'wraping around'
integrate lock to clothing
'collapsible' chain
'collapsible' wheel
display on wheel
staining lock
destroy bike remotely
new system: free bikes
5 min.
10 min.
15 min.
20 min.
25 min.
30 min.
35 min.
40 min.
45 min.
50 min.
55 min.
60 min.
65 min.
70 min.
75 min.
80 min.

ITEM	Description	Column
	Transcription 'Black' participant	PRO-00 or RCA-00 (Participants' code name)
	Transcription 'Red' participant	
	Transcription 'Blue' participant	
	Transcription Researcher	
	Protocol phase 'Conceptualisation' as designed for protocol	P
	Protocol phase 'Refinement' as designed for protocol	
	Protocol phase 'Definition' as designed for protocol	
	Trophec explorations as designed for protocol	
	Protocol phase 'Conceptualisation' as it took place	Pr
	Protocol phase 'Refinement' as it took place	
	Protocol phase 'Definition' as it took place	
	Trophec explorations as it took place	
	Computer usage - Google images	
	Computer usage - Google web search	
	Computer usage - 3D modelling and render	
	Computer usage - Key note	
	Design process stage participants were working on	L - I - C - E - D - C
	Reading the design brief	
20	Figural representation and number of chronological creation	
	Figural representation's complexity degree (grading 1 to 5 on the bottom of page)	Far ---- Close
	Figural representation's relation to vertical transformations	
	Writing complementing figural representation	
	Writing general comments, reflections and ideas	
	Computer based board	
	Sketches' link, same designer	
	Sketches' link, between different designers	
	Vertical transformation	Far ---- Close
	Lateral transformation	
padlock	Concept ideated	
1	Far - Close concurrent report first answer and working sheet number	
	Far - Close concurrent report second answer (same sheet)	
	Far - Close concurrent report third answer (same sheet)	
	Far - Close concurrent report not answered, WS pairs	
	Far - Close concurrent report not answered, WS odds	



RCA-2
P
Pr
L I C E D C
Far
Close
street post bike parking
uncuttable device
electrify bike
underground parking
1
2
3
4
F
GBR
GBR
GBR
10
5,000
GBR
97%
1%
1%
1%
GBR
GBR
GBR
GBR
GBR
10
5,000
GBR
94%
4%
1%
1%
5 min.
10 min.
15 min.
20 min.
25 min.
30 min.
35 min.
40 min.
45 min.
50 min.
55 min.
60 min.
65 min.
70 min.
75 min.
80 min.
1
2
3
4
5

ITEM	Description	Column
	Transcription 'Black' participant	PRO-00 or RCA-00 (Participants' code name)
	Transcription 'Red' participant	
	Transcription 'Blue' participant	
	Transcription Researcher	
	Protocol phase 'Conceptualisation' as designed for protocol	P
	Protocol phase 'Refinement' as designed for protocol	
	Protocol phase 'Definition' as designed for protocol	
	Trophec explorations as designed for protocol	
	Protocol phase 'Conceptualisation' as it took place	Pr
	Protocol phase 'Refinement' as it took place	
	Protocol phase 'Definition' as it took place	
	Trophec explorations as it took place	
	Computer usage - Google images	
	Computer usage - Google web search	
	Computer usage - 3D modelling and render	
	Computer usage - Key note	
	Design process stage participants were working on	L - I - C - E - D - C
	Reading the design brief	
20	Figural representation and number of chronological creation	
	Figural representation's complexity degree (grading 1 to 5 on the bottom of page)	Far ---- Close
	Figural representation's relation to vertical transformations	
	Writing complementing figural representation	
	Writing general comments, reflections and ideas	
	Computer based board	
	Sketches' link, same designer	
	Sketches' link, between different designers	
	Vertical transformation	Far ---- Close
	Lateral transformation	
padlock	Concept ideated	
1	Far - Close concurrent report first answer and working sheet number	
	Far - Close concurrent report second answer (same sheet)	
	Far - Close concurrent report third answer (same sheet)	
	Far - Close concurrent report not answered, WS pairs	
	Far - Close concurrent report not answered, WS odds	



RCA-3
P
Pr
L
I
C
E
D
C
Far
Close
front wheel immobiliser
chain in handlebar
chain in wheel's hub
remove bike part
remove handlebar
collapsing wheel
make bike unusable
1
2
GBR
BRA
BRA
10
75%
3,650
25%
GBR
collapsing handlebar
3
BRA
IND
IND
IND
15
2%
5,000
95%
USA
3%
5
F
5 min.
10 min.
15 min.
20 min.
25 min.
30 min.
35 min.
40 min.
45 min.
50 min.
55 min.
60 min.
65 min.
70 min.
75 min.
80 min.
1
2
3
4
5

6.5. - RCA TEST SUMMARY

In this test, RCA1 functioned as control group, therefore the same behaviour as the 'T' (experimental) group from Northumbria's test was expected, and which was fully achieved. This set spent a large amount of time discussing and reflecting, and even though there was good communication and dynamics among participants, they failed to reach a final decision in time to move forward a final proposal. The work output was two times greater than the other two sets. More directly relevant to the main objectives of this research, the set did not used Trophec, which supports the idea that designers do not take the initiative of incorporating sustainability criteria in early stages of design, probably because they consider the task as an assessment to make later rather than an early aid to build the ideas. Their statements in the interview support this view. Participants consider sustainability as something that should be added after the concept is defined, something 'you return to afterwards', unless the project is '100% focused on sustainability'.

The better progress in the overall test of RCA2 and RCA3 is thought not to be related to the use of Trophec, but simply because of the predetermined phases of the test, that pushed them to make commitments and faster decisions. It is highly relevant to mention the group dynamics that occurred in both sets, RCA2 was mainly managed by Blue and in RCA3 a very fluid and positive relation was built between Red and Blue, which led in both cases to easier agreements and faster decision making.

There seems to be no direct evidence of any changes in the working progress caused by Trophec: there is no fluctuation in the sketch creation, their amount or length of creation, or their level of complexity. There are no changes in the verbalisations, the rhythm and amount of which seem to be more related to the design stage, and they diminish when reaching the end. Only visible is the increase in complexity, and this can be seen in the amount of materials and manufacturing processes. However, as stated earlier, this is consistent with the nature of the design process, in which the complexity and detail of the proposal increases as it moves ahead. In RCA3 there are some interesting sketches related to the life cycle of the product, but there is no direct evidence showing that it was provoked or linked directly to Trophec, and could simply be a reaction of the task requested.

Nevertheless, it is relevant to mention that both sets that used Trophec produced final proposals from the 'built in' and 'urban' categories, which, as stated earlier, belong to a higher degree of sustainability than the 'add on', to which RCA1's final proposal belongs. In figure 6.13 p.223, it can be seen how the sets using Trophec (in purple) scored higher in 'implementation', and particularly in 'costs' and (environmental) 'impact'. These lead the author to think that the use of Trophec may induce the retrieval of information from the long-term memory that, even if not externalised in the form of verbalisations, may create connections between ideas that ultimately lead to this results. This issue will be discussed again later in this chapter, when analysing the professional designers' results (p.263), and in the next chapters for a general discussion and conclusions.

6.6. - PROFESSIONAL DESIGNERS

FLOW CHART

For this test the same flow charts as that used for the RCA were created, the only difference being in PRO1 and PRO2 protocol, where the use of Trophec was optional, working these two as control groups, both participants decided not to use the tool, and shortened the test phases, which can be clearly seen in columns 'P' and 'Pr', figure 6.21.

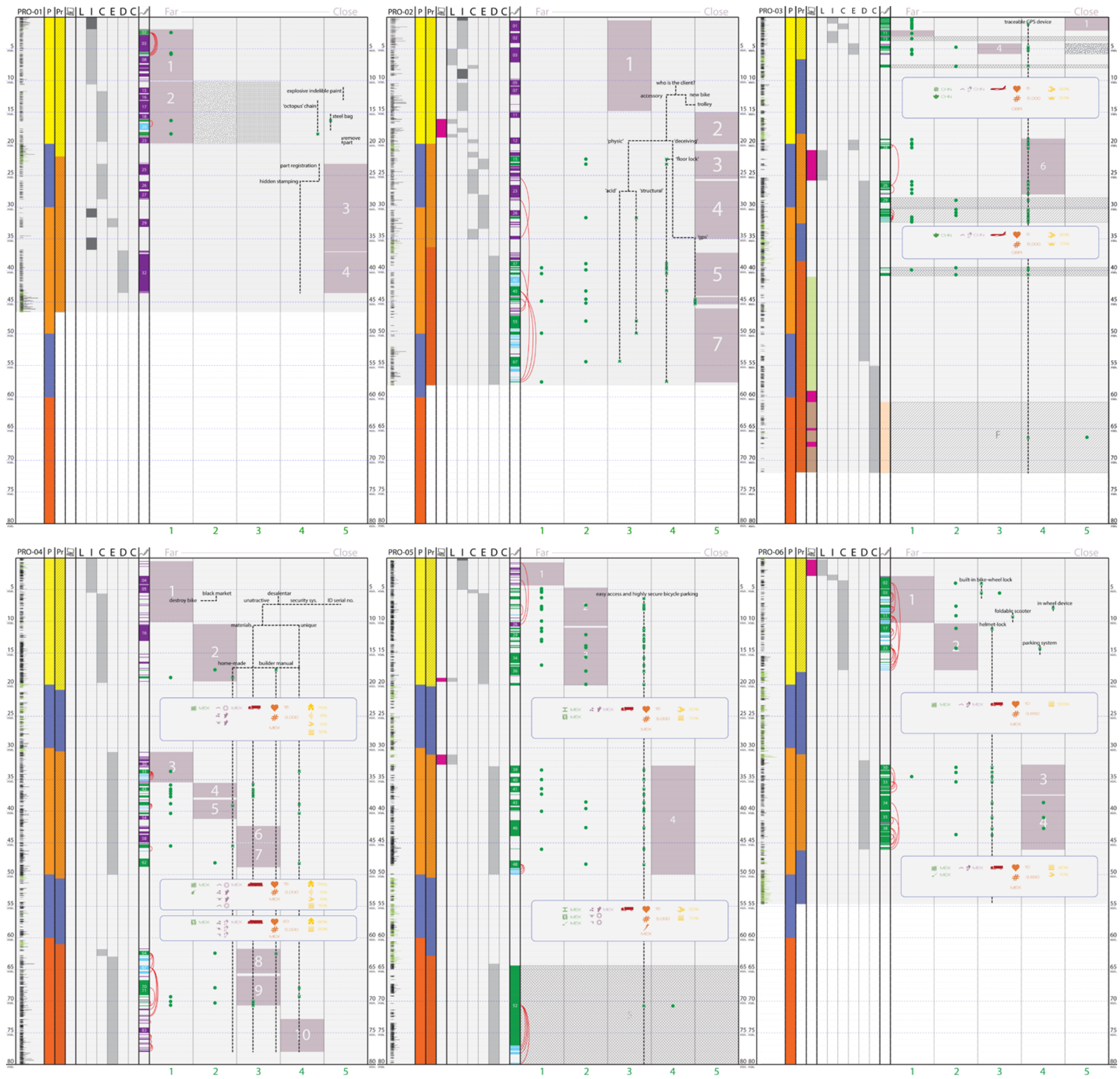


Fig. 6.21 All professionals' flow charts

SURVEY

The initial survey was also applied to professional designers. Their responses show a considerable interest in applying sustainability in their practice, but appear to find it difficult to do, with reasons ranging from lack of capacity to transmit knowledge and experience, to the fear of change they see in entrepreneurs. The latter correlated to the lack of interest from clients and companies, as well as the focus they have on cost, making sustainability appear to be an extra weight not an advantage, table 6.10.

	training in S.D?		how interested in applying sustainability in your practice?					how easy you find applying sustainability in your practice?					main reasons?
	Y	N	considerable	moderate	some	little	no	very	moderate	somehow	little	no	
PRO 1													The company is not interested in sustainability for new products
PRO 2													Companies today look for costs and don't want delays or added costs in proyects. For the insutries I know about, sustainability is a weight and non an advantage, and if I propose it I risk my proyect is rejected
PRO 3													Materials source, transport, supply chain, manufacturing infrastructure
PRO 4													Industrial process dominate, fear to change, entrepreneurs don't consider it relevant
PRO 5													In my experience many products have to comply with certain characteristics, which are convenient for the producer. It is hard to find a balance between what is useful for the user and what is convenient for the producer
PRO 6													Personal and professional interest for the environment, my capacity to transmit my knowledge and experience

Table 6.10 Initial survey questions

BRIEF GRADING

The overall score of PRO1 and PRO2 (who decided not to use Trophec, in figure 6.22 in black) is at the extremes. PRO1 is among the top ranks with 3.2 - mainly due to the low cost and simplicity of implementation, as well as the high level of sustainability in his proposal. PRO2 had the lowest average of all professionals with just 2.2, with his top score being functionality. The professionals using Trophec (in purple) all scored three points or more, with exception of PRO4, who obtained only 2.5. Clearly the complexity of his proposal was interestingly sustainable, but with strong complications of functionality, implementation and cost. PRO6 was the highest with an average of 3.3.

On average, the cost and implementation criteria do not show any significant difference between Trophec users and non-users, unlike in function and environmental impact, where the participants using Trophec score on average 12% higher, this may be signs of correlation between the use of the tool and the sustainability considerations achieved in their designs, even if not necessarily verbalised during the think aloud protocol.

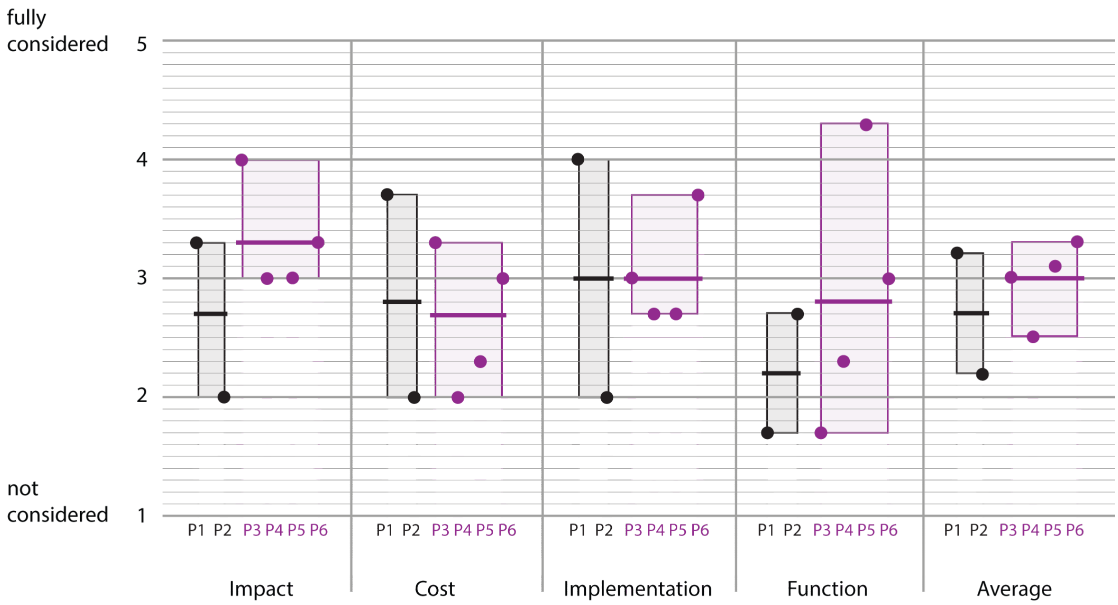


Fig. 6.22 Professional designers brief grading

SKETCH AND TRANSFORMATION ANALYSIS

There are clear different styles in sketching, one is almost purely figural with some written notes (PRO3, PRO5 and PRO6), and heavily written process (PRO2 and PRO4) up to almost exclusively written (PRO1), figure 6.23. An interesting issue was identified when reviewing all processes together. There were two designers who produced several, almost unrelated concepts, and after an event selected one and continue to develop just that one (PRO1 and PRO6). Another two designers produced several ideas (almost all were product of lateral transformations), and decided to take forward four different ideas all the way to the end (PRO2 and PRO4). Lastly another two designers who very early on produced one concept only, stuck to it, developing it for the rest of the test (PRO3 and PRO5). Curiously there seems to be a correlation between the designers matching each approach type: PRO1 and PRO6 are employees of large companies, PRO2 and PRO4 are independent consultants, PRO3 is an entrepreneur, designing and commercialising his own products and PRO5 is dedicated almost exclusively to the aesthetic refinement of already defined products. Furthermore, looking at the brief grading, this apparent correlation takes other perspective; PRO1 and PRO6 have the highest scores, PRO2 and PRO4 the lowest, finally PRO3 and PRO5 are in between. This issue will be discussed further in chapter eight and nine.

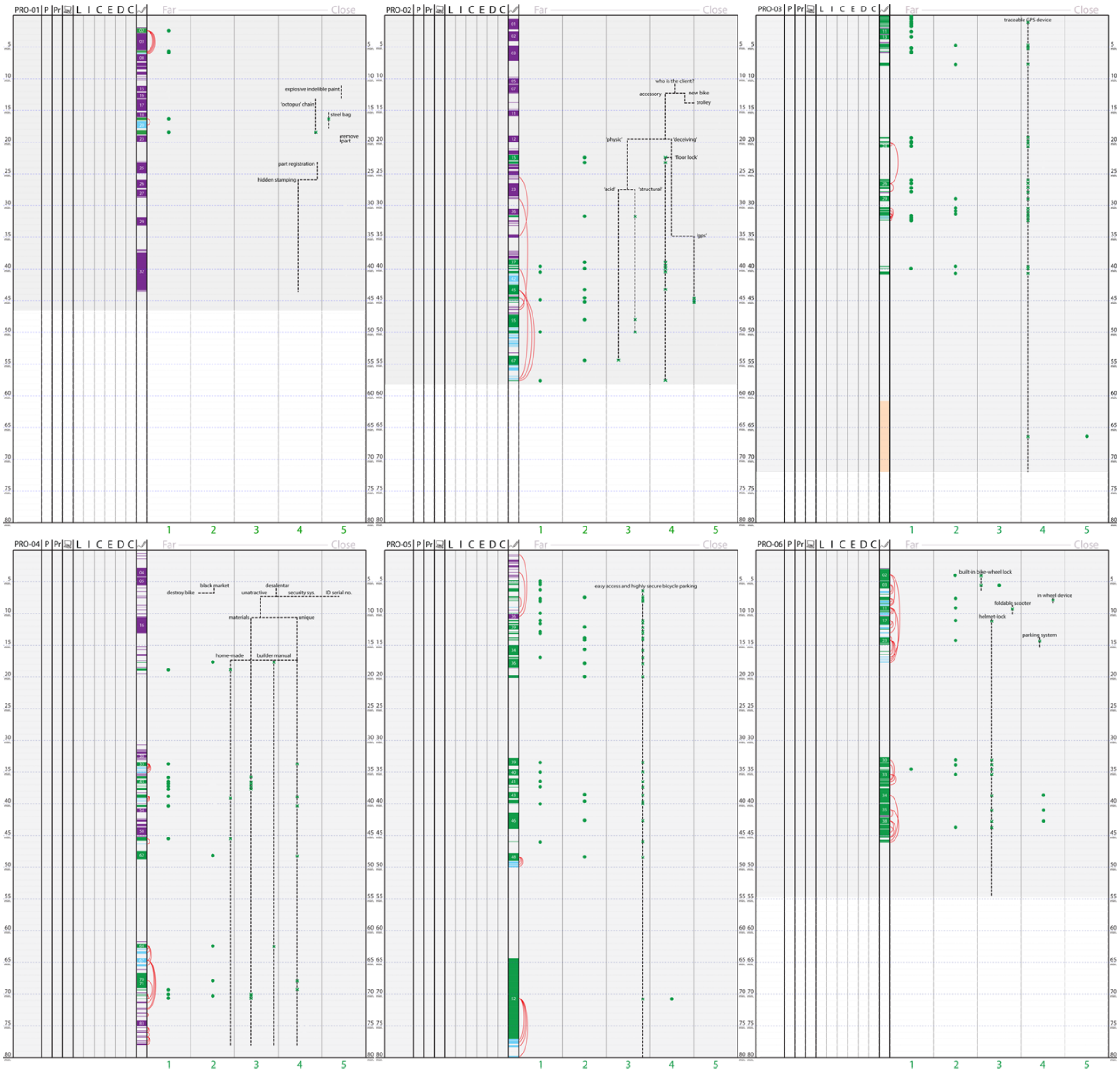


Fig. 6.23 Professional designers sketches and transformations

PRO1 wrote almost all that he was verbalising, creating just four figural representations, all of complexity level one, with only two of them belonging to an actual new concept development. There are very few links between sketches. As mentioned previously PRO1 generated six different concepts, all unrelated, and just one lateral transformation, which eventually became the final proposal. He also refused to perform the third phase of the test (definition) arguing that he had already finished, and he lacked the knowledge and the skills to move forward the idea. According to the statements from the interview, which will be analysed in following sections, PRO1 works in what it seems to be a very compartmentalised company. His reaction is believed to be a developed natural behaviour, focusing exclusively in his obligations and referring any other issue to other specialists within the company.

Similar to PRO1, PRO2 started producing heavily written expressions; the first concept came about in minute ten, followed by a complex development of other concepts and lateral transformations. In total ten concepts with seven lateral transformations were detected. Also noticeable is the change to figural representations in the last third of the test, as well as the links between sketches. Most of the sketches are of complexity level two, with only five of level one produced in the last third of the test. PRO2 works as an independent consultant, his process was complex and trying to cover several possible aspects of the challenge, he even defined who his client was, indicating a particular approach where satisfying the expectations of the client was primordial.

PRO3 first expressed what he thought was the way to proceed, making the argument that a 'prohibitionist' approach has proven not to work, and by doing this he defined his theme in the first two minutes of the test. All this previous analysis, and subsequent development was done almost exclusively with figural representations and verbalisations, and very few links between sketches. Only one concept was generated, which was developed to a high detail during the rest of the test. PRO3 is a designer entrepreneur, he clearly look for the most feasible solution quickly and then dedicated the rest of the time to define the idea as much as possible, which probably is his approach to his real life projects where certainty and feasibility for his investment are the focus.

PRO4 started doing an almost purely written analysis, in which all of his concepts came to be. In total 10 concepts could be identified, most of them the product of lateral transformations. All concepts were produced before finishing the first phase of the test. In the second and third phase the amount of figural representations increased, as well as the links between them and their level of complexity, which only reached level two. This participant decided to move forward four complementary concepts all the way to the end. PRO4's process is very similar to PRO2, and both are independent consultants, where a wide variety of solutions provide a safer context when facing a client.

PRO5 began with a written analysis of the current situation and probable solutions. The first figural representation came about only at minute five, almost together with the only concept he produced and kept on working till the end of the test. After that it was almost exclusively figural representations, with just some notes complementing the sketches. The complexity of sketches alternated between one and two from the outset. Noticeably the last sketch, made to communicate the concept, required some embodiment definition, and took a very long time; almost thirteen minutes and reached the complexity level four. This participant was the only one that erased drawings.

PRO6 immediately started with figural representations, some of which were accompanied by notes that also explained the high degree of linkage between sketches. PRO6 performed an early search for concepts, and produced five unrelated ideas. He shows only vertical transformations, all of them taking place before the first exploration with Trophec. The use of the tool influenced his decision about which of the solutions created was selected as the final one. Two more sheets of sketches were then produced - all of them defining the final concept. The complexity of sketches was high from the beginning, with mostly level two and one level three, reaching level four towards the end.

CONCURRENT REPORT

Professional designers do not seem to be different from students in the use of working sheets, using from four up to ten sheets, almost all showing a progressive movement from 'far' to 'close'. PRO1 was the exception, jumping dramatically from 'far' to 'close' from sheet two to sheet three. This seems to be a reaction to his decision as to which idea to develop, therefore he felt 'far' when looking for concepts, then once a selection was made he was 'close', and became just a matter of definition. PRO2 started mid way, and already in sheet two jumped to 'close' and stayed there for the rest of the test, seemingly similar to PRO1. In table 6.11 the moments in which the explorations with Trophec took place are shown with blue vertical lines.

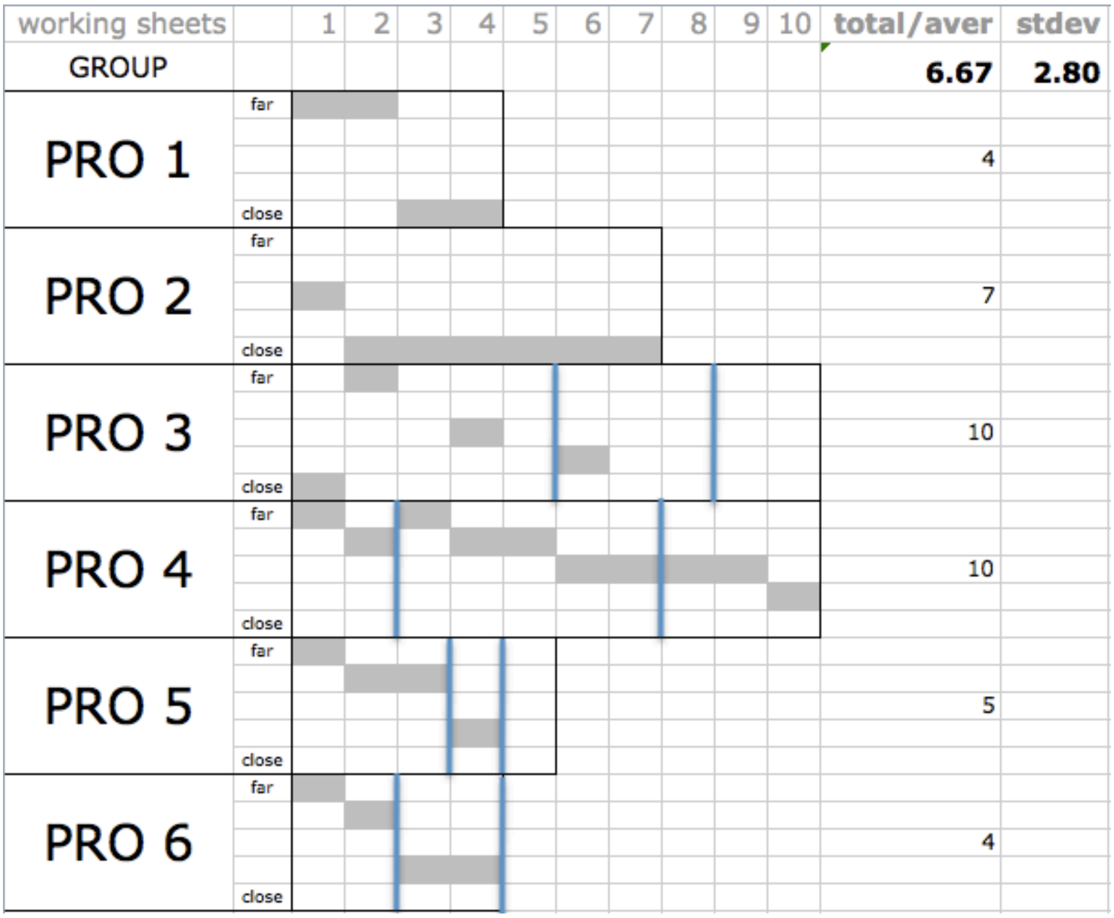


Table 6.11 Professionals' concurrent reports, blue line indicates Trophec usage

PRO3's concurrent report shows first a 'close' statement, this was done while reflecting on the path he thought it was better to follow. The second sheet was used to explore other possibilities, like existing padlocks, but in a rhetorical way only. When doing this he expressed that using any of those 'classic' approaches made him feel 'far', and for that reason crossed that box in sheet two. Later he returned to develop his idea that then showed the 'normal' progress towards 'close'.

As expected PRO4 started by crossing the 'far' option in sheet one. Later, when he had all his concepts produced he moved one box towards 'close'. Between sheet two and three the first exploration with Trophec took place, in which the participant realised that some of the decisions taken, particularly in material selection, did not allow him to finish the cycle of the product as he wanted, which made him again mark 'far' in working sheet three. This is one of the strongest evidence found about the tool affecting the working process. The rest was a slow progression towards 'close' that was not completely reached. This participant used ten working sheets and took the precaution of adding the concurrent report on the extra sheets himself.

PRO5 followed the expected progressive sequence starting at 'far' and moving towards 'close'. Nevertheless he remained near to 'far' in sheet two and three, lastly near to 'close' in sheet four. This happened after the first exploration in Trophec, where he declared that he had learnt specific issues about the impossibility of recycling concrete, which made him change his decision. Sheet five was used for the final sketch and no box was crossed.

Again the expected progress from 'far' to 'close' is found also in PRO6, with the only noticeable fact being that after Trophec's first exploration he jumped to the box before 'close', due to the fact that the analysis of materials and recyclability led him to more quickly decide for one of the generated concepts.

VERBALISATIONS AND RETROSPECTIVE REPORT

In all cases verbalisations were continuous and fluid, which helped identify the design steps to which they were working. All reached the 'definition' step, with exception of PRO3, who arrived at 'communicating' and PRO4 who remained in 'exploration'. Noticeably PRO1 and PRO4 did not use the computer at all. This was not the case of PRO3, whose 'exploration' was very long and took him to use a 3D modelling software (Modo) and a presentation software (Keynote) to build his final presentation board. Similarly, PRO5 also had a very long exploration phase. It is also interesting that PRO6 jumped from 'conceptualisation' to 'definition' and did not 'explore' at all his concept, and following the previously mentioned match, PRO1's 'exploration' step was by several times shorter than the rest (figure 6.24).

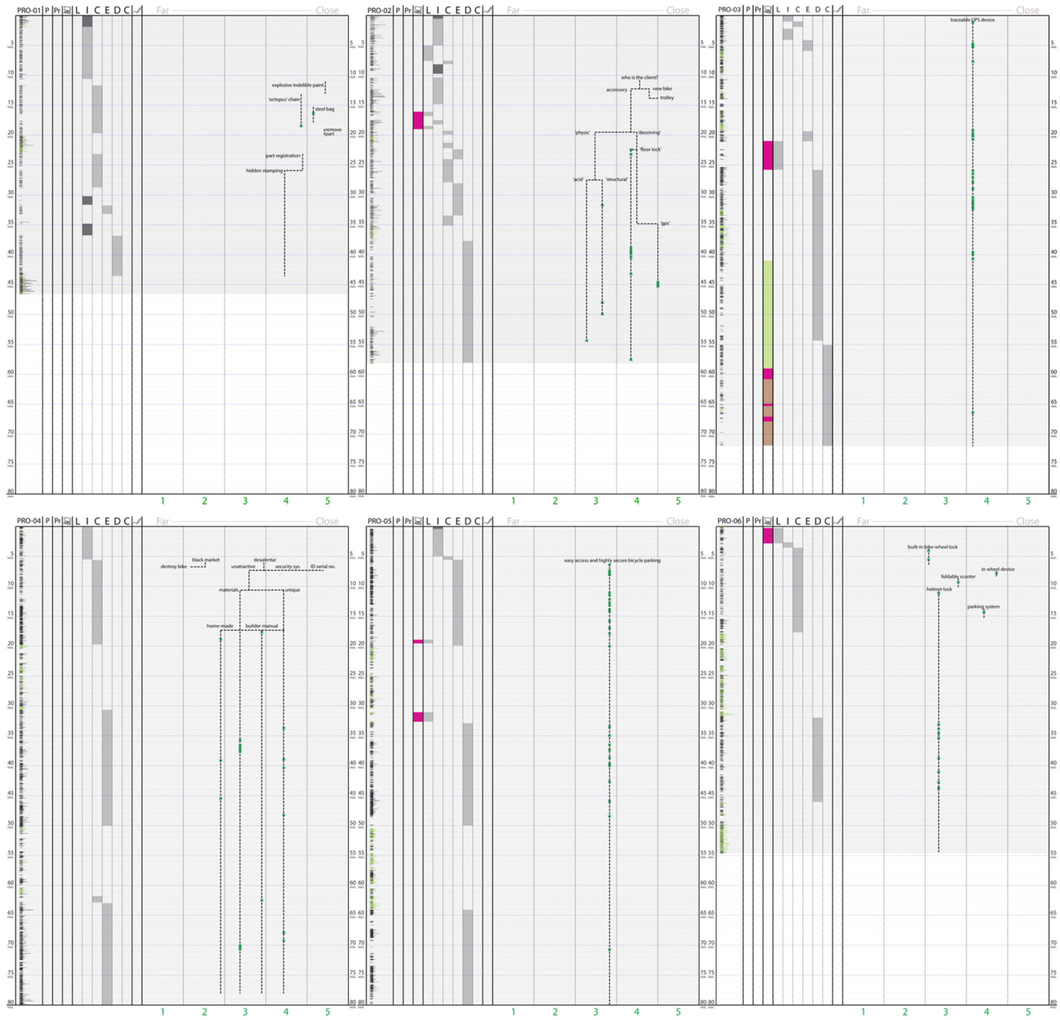


Fig. 6.24 Professional designers transcription, design process steps and transformations

For PRO1 the dialogue was fluid, the only period where it clearly diminishes is when entering the 'exploration' step, when he stops and reads the brief two times for around four minutes in total. Once finished he starts to define the particulars of his proposal. In general a progressive sequence of the design steps can be seen. PRO1 did not used Trophec.

PRO2 had a rich verbalisation, with some silences towards the end. The process was a progressive and sequential one that took him up to 'definition'. He probably did not make it to communicating because he decided to move forward four ideas at the same time. He used Google images for three minutes around minute sixteen. PRO 2 did not use Trophec.

As mentioned previously the process started very quickly for PRO3, the steps of identifying the problem and conceptualisation were finished within the first four minutes of the test. Exploration was also rather short, due to the clarity and definition level of the original concept. Therefore, the rest of the test was dedicated to the definition and communication of the final concept. Noticeably this designer used Google images before starting the definition step; the reason given was to find the best location for the device he had ideated. Later the computer was used again in order to create a 3D model of the device with several of its components. Again Google images were searched, this time to look for images to use in his final presentation board, which was assembled using Keynote software. He was the only participant of all tests that reached this level of definition and work.

The dialogue was clear and abundant in PRO4, with minor silent periods. The general process was slow especially during the last two thirds, first dedicating five minutes to identifying the problem, later almost fifteen minutes for conceptualisation. The rest of the test was an exploration of the four different concepts he produced.

PRO5's dialogue was clear and abundant, showing some long silence periods towards the end of the test, similar to other participants. PRO5 started with a five-minute period for identifying the problem, mainly with written statements. A very short conceptualisation period followed, which led to more than ten minutes of exploration, at the end of which he searched images in Google. Returning from the first exploration in Trophec he again opened Google images in order to understand how to adapt his design to the different sizes and forms of bicycles. Immediately thereafter he started the definition, which lasted until the end of the test.

In PRO6 case the dialogue is more balanced, there were short silent periods equally distributed throughout the test. PRO6 started the test with a search of Google images related to existing similar products. This was followed by a short (one minute) period to identify the problem; he then dedicated around fourteen minutes to search for concepts. In this period he created five unrelated concepts, all with some vertical transformations. After Trophec's first exploration he selected the helmet concept and jumped directly to definition, when he drew more technical visualisations of the product: lateral, top and frontal views.

TROPHEC

In all cases the increase of materials and manufacturing processes in the second exploration is noticeable, which again is consistent with the nature of the design process itself. There is nevertheless one exception, PRO3, who decided to remove one material from the cycle because it 'exceeded in weight' his needs, figures 6.25 and 6.26.

Fig 6.25 Left Pro 3 Trophec cycles, on top first exploration, bottom second exploration. Right Pro 4 Trophec cycles, on top first exploration, bottom second exploration

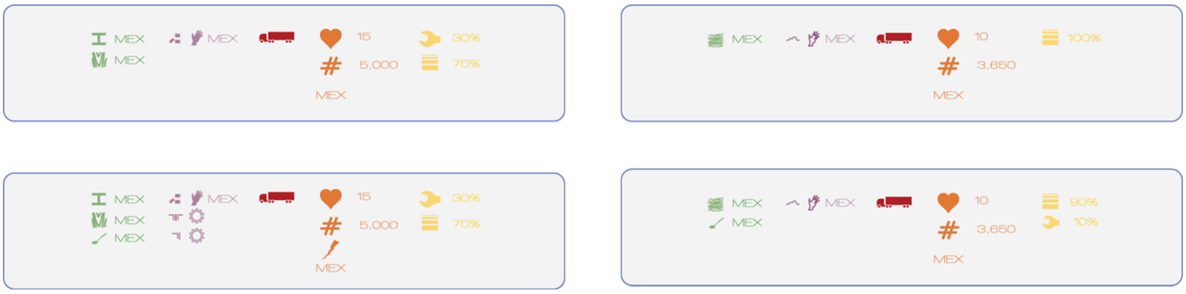


Fig 6.26 Left Pro 5 Trophec cycles, on top first exploration, bottom second exploration. Right Pro 6 Trophec cycles, on top first exploration, bottom second exploration

PRO1 refused to use Trophec, in the first exploration on the grounds of not having an idea to assess, and in the second exploration because his proposal was not an object, but a step in the manufacturing process.

PRO2 did not use Trophec, arguing in the first exploration that for what he was working on, it was not useful. He had finished working sheet two, where he had decided very broad concept categories to develop, rather than any precise idea. In the second exploration he simply said that he did not want to use Trophec, which he saw as adding another complication to the process. At this point he already had some of the concept embodied in clear design proposals.

As described in chapter five section 5.7 p.165, PRO3, when using Trophec made some important realisations about the environmental (non recyclability of certain materials or the toxicity of batteries) and social impact (potential child labour or slavery in China) of his product. But this made no difference in his final design. Unlike the other participants, this participant's first and second explorations did not increase in complexity. It seems that the designer had a very clear image of his product very early on; thus making him impervious to any external influence.

In the case of PRO4 the expected increase in complexity appears in the form of more materials and manufacturing processes, but because of his complex solution based in four different but related concepts, he decided to produce two different cycles in the second exploration, which increased the complexity even further. He was the only one to produce two cycles in one exploration.

As expected the level of complexity increased between first and second exploration. PRO5 demonstrated one of the clearest influences of Trophec - the realisation of the recyclability characteristics of materials and subsequent changes to improve sustainability without affecting performance or function; this was identified exclusively through his verbalisations. His design embodiment did not change as a result of this influence, which ultimately allowed him to avoid any part of his product finishing up in landfill. In some statements during the think aloud, he defined the government as the 'owner' of the object, somehow ensuring the appropriate dismantling, disassemble and recycling of the product.

For PRO6 there was only one change between first and second explorations - the addition of stainless steel in the materials selection. This happened when he realised that the product needed a locking system. For the rest of the product natural fibres were selected, which initially made him select 100% compostable, later he added the metallic part therefore diverting 10% of recycling to producers.

INTERVIEWS

As stated previously, even if the test was divided in the three same phases as RCA's test, the use of Trophec for PRO1 and PRO2 was entirely optional. This was done this time as a control group in order to identify the reactions of professional designers to the task of voluntarily incorporating sustainability criteria in the early stages of design. Both refused the use of the tool arguing that they did not need it, and that it would, unnecessarily, increase the complexity of the project. All other participants were asked to dedicate the time to use Trophec, and given the option of creating a new cycle or just consulting the glossary information; this last option was given in the case of finding impossible to produce a cycle of something not yet defined, and it was an important part of the test that helped overcome the preconceived idea of needing a defined design in order to create a life cycle.

A common refrain from almost all participants was the fact that in a company the tasks are divided among different departments, that designers have a limited capacity, that there was a lack of demand from both market and clients, and that the inclusion of sustainability criteria should start from the company's overall culture, which confirms the findings in the literature review.

PRO1 produced one of the most interesting interviews of all professionals, as he explained in great detail many of the complexities within the company he works for, and how designers have a very limited reach within it. He asserted that no one knows or deals with the entire process; even less connects the different departments. Finally he proposed that a software like Trophec should be able to be completed by the relevant department responsible at each stage of new product development.

Interestingly PRO2 pointed out that designers have a 'working culture' where some things are simply not considered, and that sustainability is normally seen by clients as an expensive 'add on'. He also addressed the issue that Trophec should not only be directed at designers, but also at marketers and managers, making reference to the numerous decisions that are made outside design.

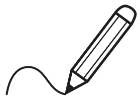
When confronted in the interview about the lack of reaction from the factors encountered with Trophec, PRO3 argued that in a real life project he would have the chance to make a more detailed selection of providers in order to avoid the mentioned social issues. He also declared that there was an unavoidable fact, that Chinese providers were more reliable.

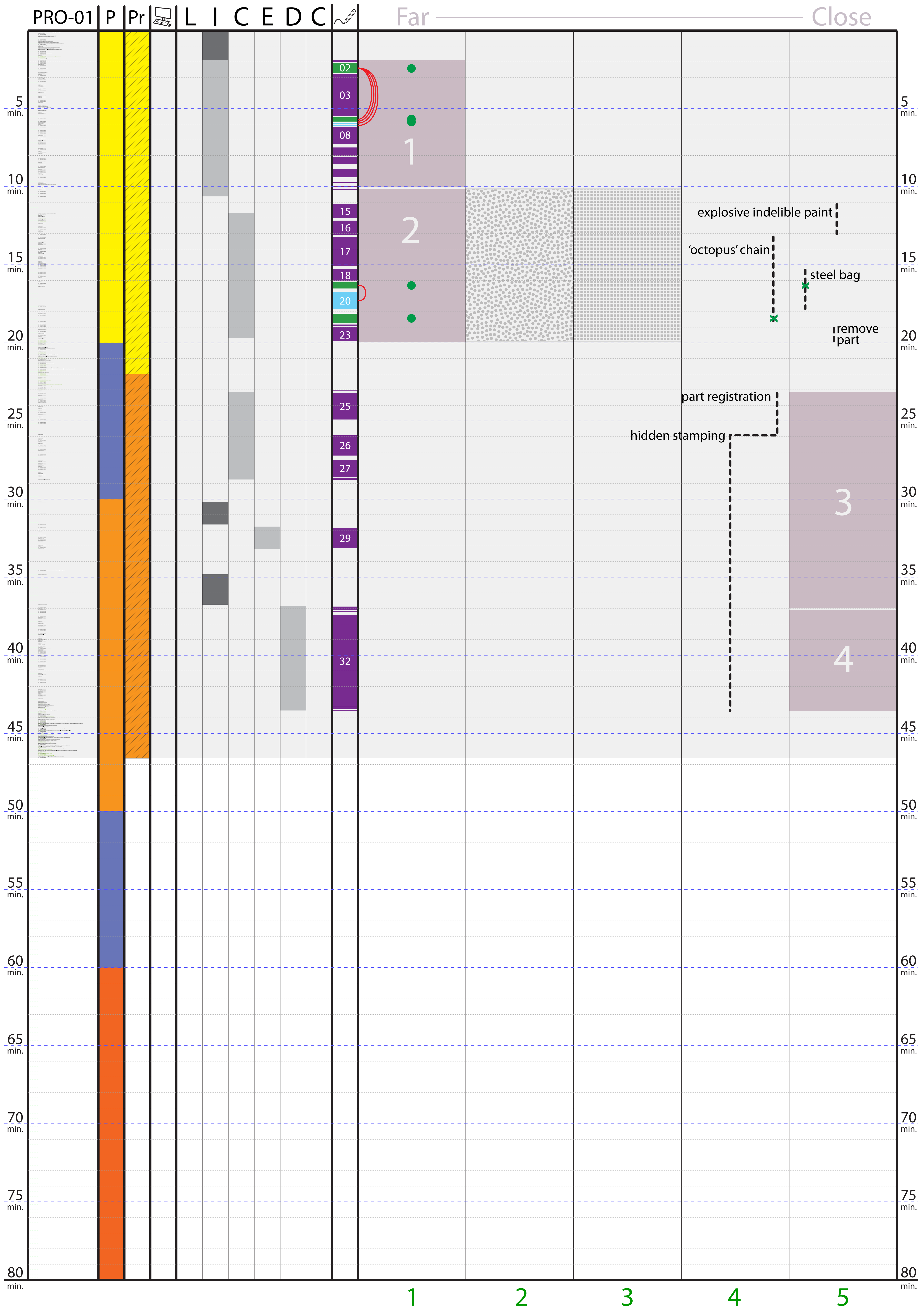
PRO4 is an independent consultant. He mentioned the difference between new start-ups and well-established entrepreneurs: in the former opportunities exist for designers to propose beyond the product and into the business model itself, the latter 'do not have the openness to understand it'.

Beyond the already described realisations about the material's recyclability, PRO5 also made reference to the limited capacity of designers to make changes in a product's design, stating that many design decisions were made before producing the design brief.

PRO6, who like PRO1 works in a large company, also commented about the limited capacity of designers to define the whole of the product, and identified management as one of those responsible for some of these decisions.

The full charts in A3 size for all professional designers can be found in the next pages.

ITEM	Description	Column
	Transcription 'Black' participant	PRO-00 or RCA-00 (Participants' code name)
	Transcription 'Red' participant	
	Transcription 'Blue' participant	
	Transcription Researcher	
	Protocol phase 'Conceptualisation' as designed for protocol	P
	Protocol phase 'Refinement' as designed for protocol	
	Protocol phase 'Definition' as designed for protocol	
	Trophec explorations as designed for protocol	
	Protocol phase 'Conceptualisation' as it took place	Pr
	Protocol phase 'Refinement' as it took place	
	Protocol phase 'Definition' as it took place	
	Trophec explorations as it took place	
	Computer usage - Google images	
	Computer usage - Google web search	
	Computer usage - 3D modelling and render	
	Computer usage - Key note	
	Design process stage participants were working on	L - I - C - E - D - C
	Reading the design brief	
20	Figural representation and number of chronological creation	
	Figural representation's complexity degree (grading 1 to 5 on the bottom of page)	Far ---- Close
	Figural representation's relation to vertical transformations	
	Writing complementing figural representation	
	Writing general comments, reflections and ideas	
	Computer based board	
	Sketches' link, same designer	
	Sketches' link, between different designers	
	Vertical transformation	Far ---- Close
	Lateral transformation	
padlock	Concept ideated	
1	Far - Close concurrent report first answer and working sheet number	
	Far - Close concurrent report second answer (same sheet)	
	Far - Close concurrent report third answer (same sheet)	
	Far - Close concurrent report not answered, WS pairs	
	Far - Close concurrent report not answered, WS odds	



PRO-01
P
Pr
L
I
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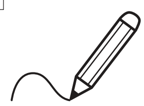
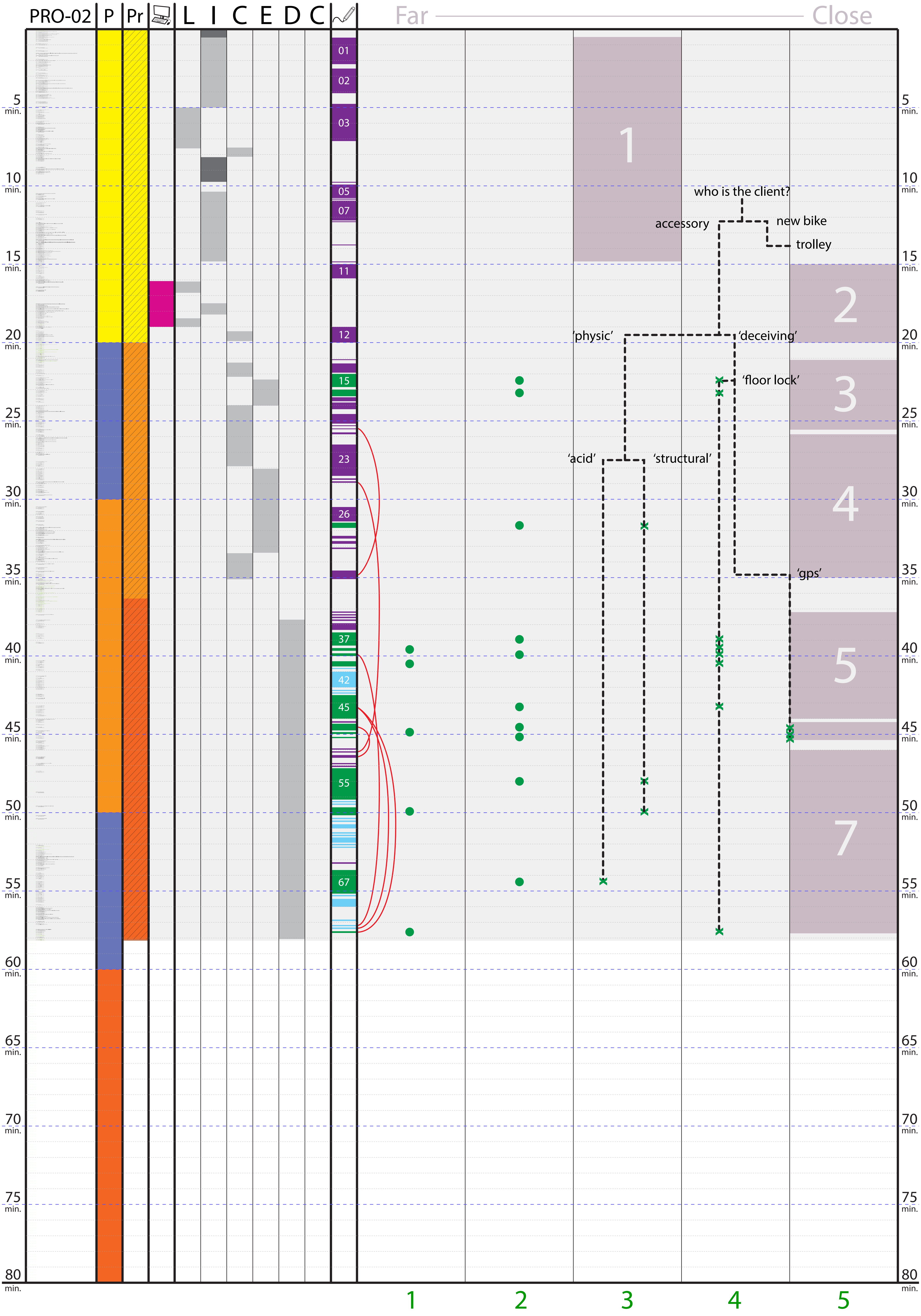
E
D
C
Far
Close
02
03
08
15
16
17
18
20
23
25
26
27
29
32
1
2
3
4
explosive indelible paint
'octopus' chain
steel bag
remove part
part registration
hidden stamping
5 min.
10 min.
15 min.
20 min.
25 min.
30 min.
35 min.
40 min.
45 min.
50 min.
55 min.
60 min.
65 min.
70 min.
75 min.
80 min.
1
2
3
4
5

ITEM	Description	Column
	Transcription 'Black' participant	PRO-00 or RCA-00 (Participants' code name)
	Transcription 'Red' participant	
	Transcription 'Blue' participant	
	Transcription Researcher	
	Protocol phase 'Conceptualisation' as designed for protocol	P
	Protocol phase 'Refinement' as designed for protocol	
	Protocol phase 'Definition' as designed for protocol	
	Trophec explorations as designed for protocol	
	Protocol phase 'Conceptualisation' as it took place	Pr
	Protocol phase 'Refinement' as it took place	
	Protocol phase 'Definition' as it took place	
	Trophec explorations as it took place	
	Computer usage - Google images	
	Computer usage - Google web search	
	Computer usage - 3D modelling and render	
	Computer usage - Key note	
	Design process stage participants were working on	L - I - C - E - D - C
	Reading the design brief	
20	Figural representation and number of chronological creation	
	Figural representation's complexity degree (grading 1 to 5 on the bottom of page)	Far ---- Close
	Figural representation's relation to vertical transformations	
	Writing complementing figural representation	
	Writing general comments, reflections and ideas	
	Computer based board	
	Sketches' link, same designer	
	Sketches' link, between different designers	
	Vertical transformation	Far ---- Close
	Lateral transformation	
padlock	Concept ideated	
1	Far - Close concurrent report first answer and working sheet number	
	Far - Close concurrent report second answer (same sheet)	
	Far - Close concurrent report third answer (same sheet)	
	Far - Close concurrent report not answered, WS pairs	
	Far - Close concurrent report not answered, WS odds	



PRO-02
P
Pr
L
I
C
E
D
C
Far
Close
1
2
3
4
5
7
who is the client?
accessory
new bike
trolley
'physic'
'deceiving'
'floor lock'
'acid'
'structural'
'gps'
01
02
03
05
07
11
12
15
23
26
37
42
45
55
67
5 min.
10 min.
15 min.
20 min.
25 min.
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35 min.
40 min.
45 min.
50 min.
55 min.
60 min.
65 min.
70 min.
75 min.
80 min.
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3
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	Transcription 'Blue' participant	
	Transcription Researcher	
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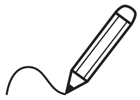
	Protocol phase 'Refinement' as designed for protocol	
	Protocol phase 'Definition' as designed for protocol	
	Trophec explorations as designed for protocol	
	Protocol phase 'Conceptualisation' as it took place	Pr
	Protocol phase 'Refinement' as it took place	
	Protocol phase 'Definition' as it took place	
	Trophec explorations as it took place	
	Computer usage - Google images	
	Computer usage - Google web search	
	Computer usage - 3D modelling and render	
	Computer usage - Key note	
	Design process stage participants were working on	L - I - C - E - D - C
	Reading the design brief	
20	Figural representation and number of chronological creation	
	Figural representation's complexity degree (grading 1 to 5 on the bottom of page)	Far ---- Close
	Figural representation's relation to vertical transformations	
	Writing complementing figural representation	
	Writing general comments, reflections and ideas	
	Computer based board	
	Sketches' link, same designer	
	Sketches' link, between different designers	
	Vertical transformation	Far ---- Close
	Lateral transformation	
padlock	Concept ideated	
1	Far - Close concurrent report first answer and working sheet number	
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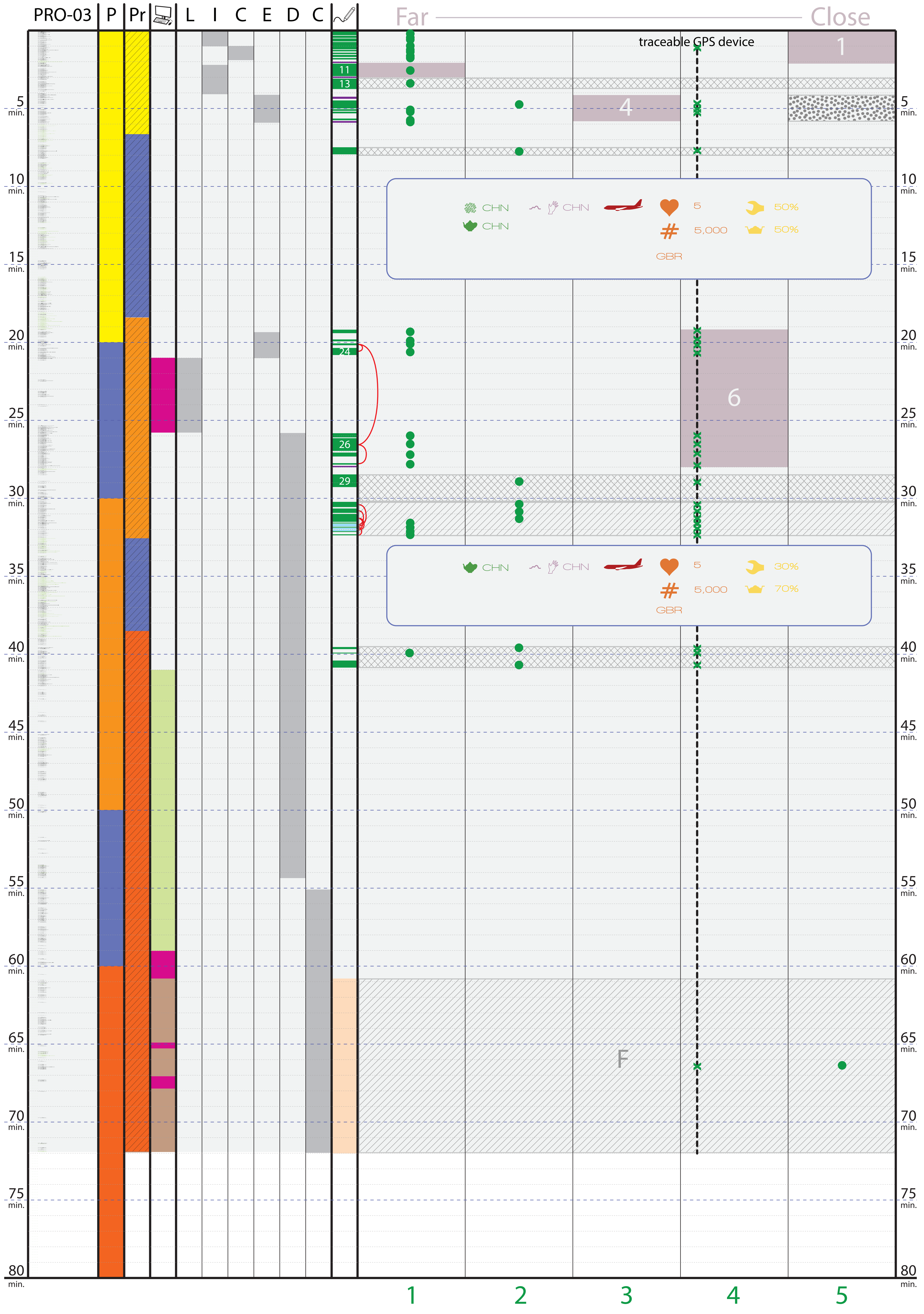
	Far - Close concurrent report third answer (same sheet)	
	Far - Close concurrent report not answered, WS pairs	
	Far - Close concurrent report not answered, WS odds	



PRO-03
P
Pr
L
I
C
E
D
C
Far
Close
traceable GPS device
1
4
6
F
11
13
24
26
29
CHN
CHN
CHN
5
5,000
GBR
50%
50%
CHN
CHN
5
5,000
GBR
30%
70%
5 min.
10 min.
15 min.
20 min.
25 min.
30 min.
35 min.
40 min.
45 min.
50 min.
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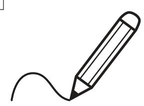
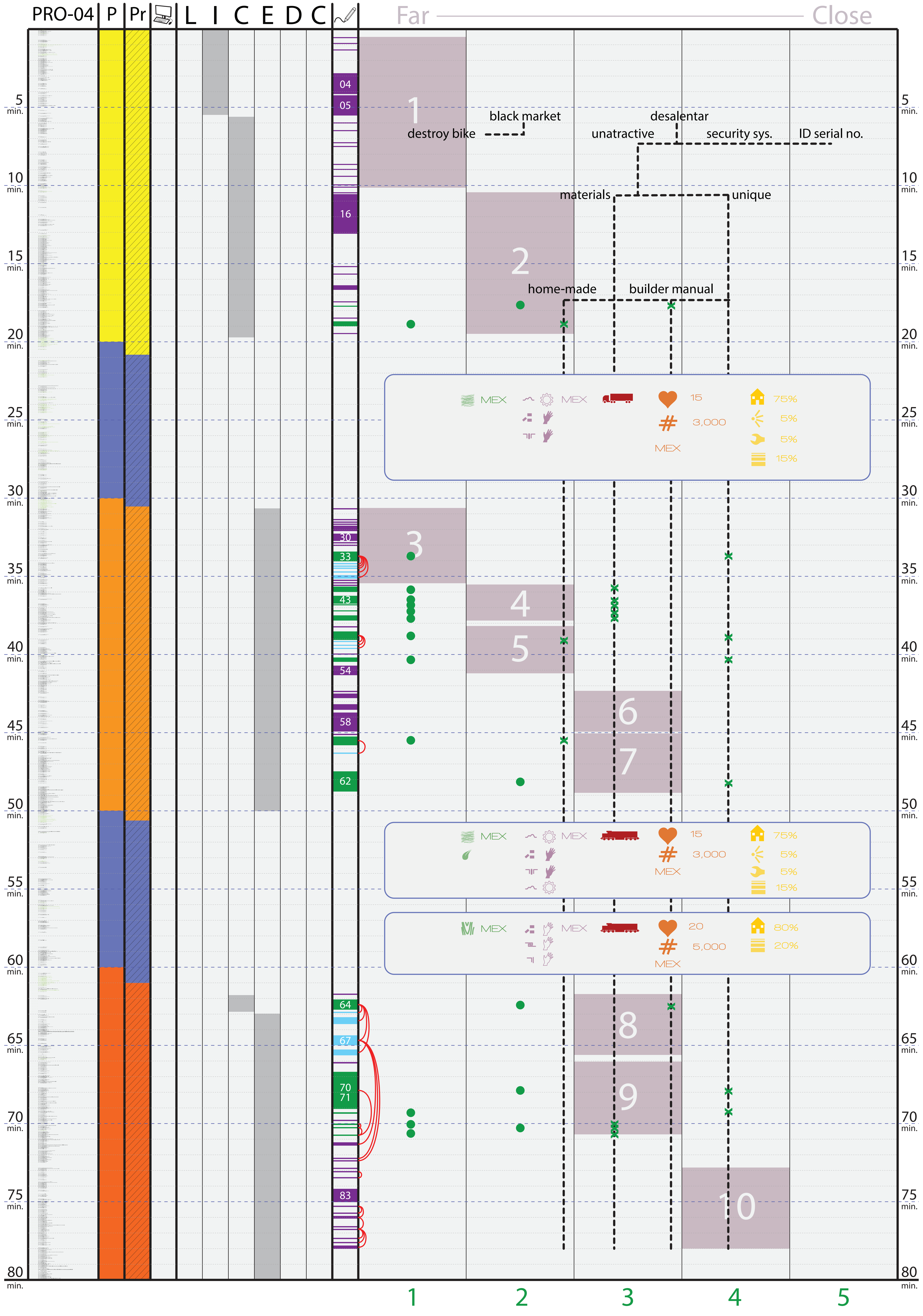
	Transcription 'Blue' participant	
	Transcription Researcher	
	Protocol phase 'Conceptualisation' as designed for protocol	P
	Protocol phase 'Refinement' as designed for protocol	
	Protocol phase 'Definition' as designed for protocol	
	Trophec explorations as designed for protocol	
	Protocol phase 'Conceptualisation' as it took place	Pr
	Protocol phase 'Refinement' as it took place	
	Protocol phase 'Definition' as it took place	
	Trophec explorations as it took place	
	Computer usage - Google images	
	Computer usage - Google web search	
	Computer usage - 3D modelling and render	
	Computer usage - Key note	
	Design process stage participants were working on	L - I - C - E - D - C
	Reading the design brief	
20	Figural representation and number of chronological creation	
	Figural representation's complexity degree (grading 1 to 5 on the bottom of page)	Far ---- Close
	Figural representation's relation to vertical transformations	
	Writing complementing figural representation	
	Writing general comments, reflections and ideas	
	Computer based board	
	Sketches' link, same designer	
	Sketches' link, between different designers	
	Vertical transformation	Far ---- Close
	Lateral transformation	
padlock	Concept ideated	
1	Far - Close concurrent report first answer and working sheet number	
	Far - Close concurrent report second answer (same sheet)	
	Far - Close concurrent report third answer (same sheet)	
	Far - Close concurrent report not answered, WS pairs	
	Far - Close concurrent report not answered, WS odds	


PRO-04
P
Pr
L I C E D C
Far
Close
5 min.
10 min.
15 min.
20 min.
25 min.
30 min.
35 min.
40 min.
45 min.
50 min.
55 min.
60 min.
65 min.
70 min.
75 min.
80 min.
04
05
16
30
33
43
54
58
62
64
67
70
71
83
1
2
3
4
5
6
7
8
9
10
destroy bike
black market
desalentar
unatractive
security sys.
ID serial no.
materials
unique
home-made
builder manual
MEX
15
3,000
75%
5%
5%
15%
20
5,000
80%
20%
1
2
3
4
5

ITEM	Description	Column
	Transcription 'Black' participant	PRO-00 or RCA-00 (Participants' code name)
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	Transcription 'Blue' participant	
	Transcription Researcher	
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	Trophec explorations as designed for protocol	
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	Protocol phase 'Refinement' as it took place	
	Protocol phase 'Definition' as it took place	
	Trophec explorations as it took place	
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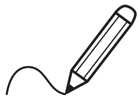
	Computer usage - Google web search	
	Computer usage - 3D modelling and render	
	Computer usage - Key note	
	Design process stage participants were working on	L - I - C - E - D - C
	Reading the design brief	
20	Figural representation and number of chronological creation	
	Figural representation's complexity degree (grading 1 to 5 on the bottom of page)	Far ---- Close
	Figural representation's relation to vertical transformations	
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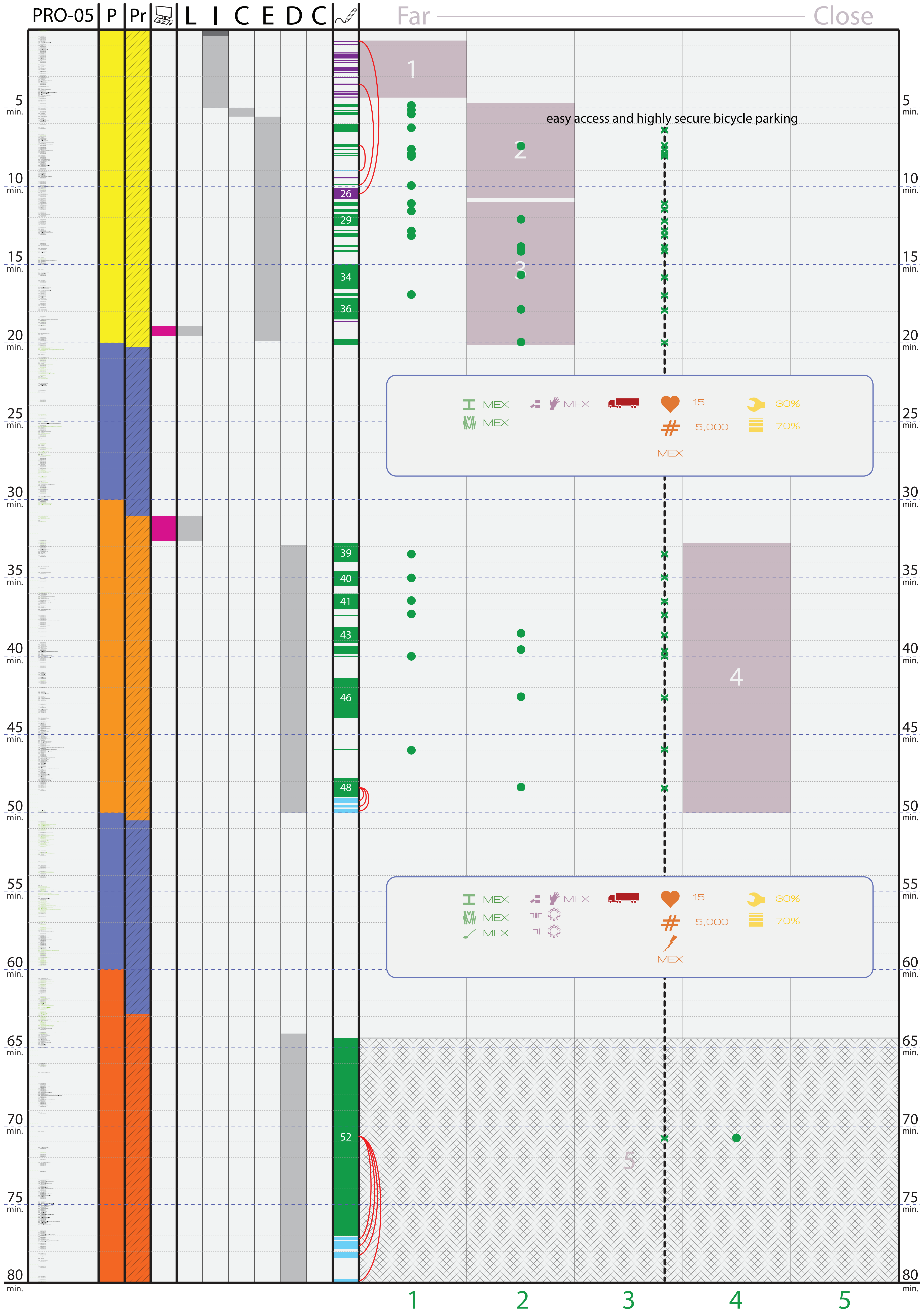
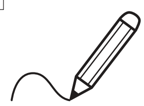
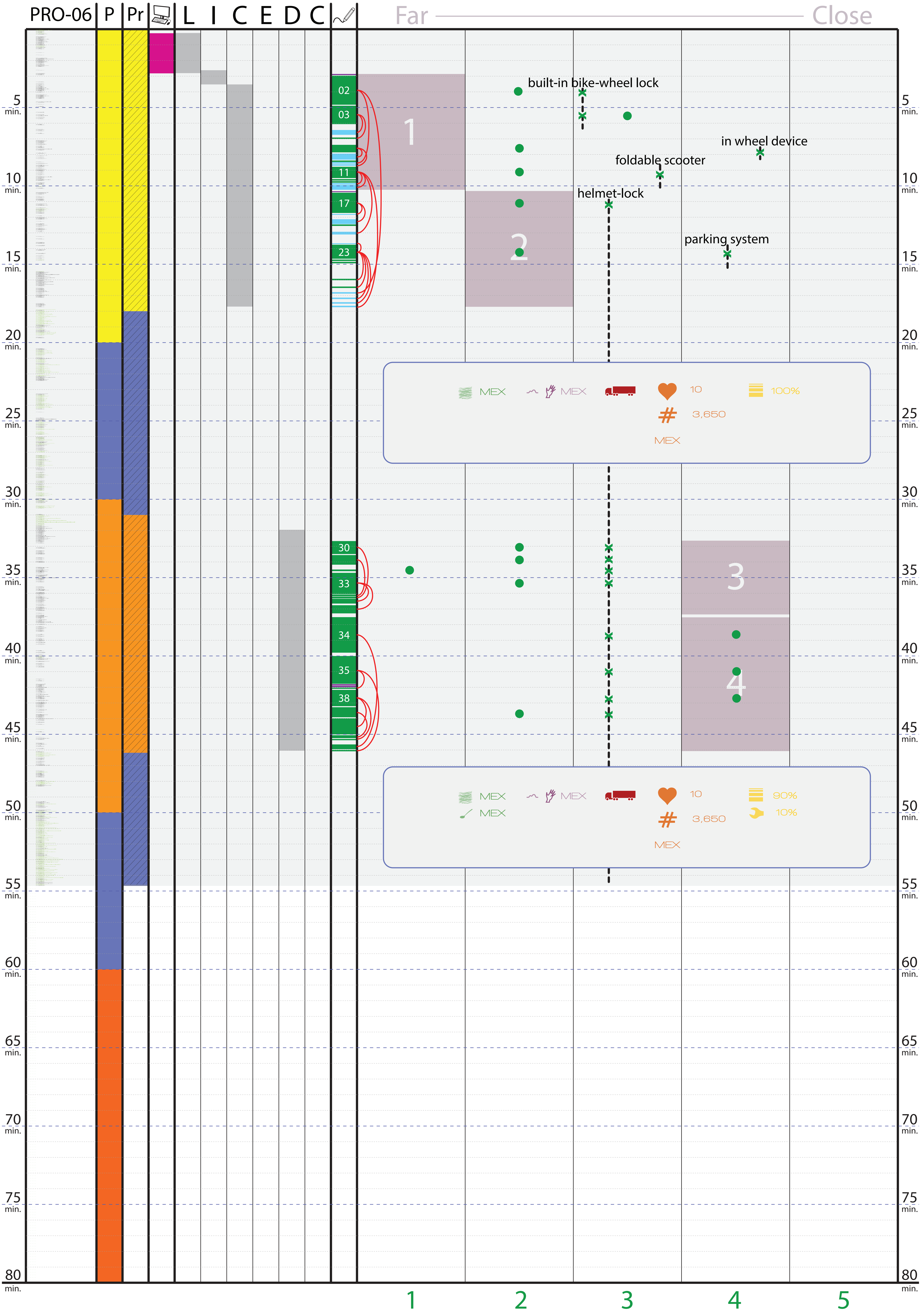
	Writing general comments, reflections and ideas	
	Computer based board	
	Sketches' link, same designer	
	Sketches' link, between different designers	
	Vertical transformation	Far ---- Close
	Lateral transformation	
padlock	Concept ideated	
1	Far - Close concurrent report first answer and working sheet number	
	Far - Close concurrent report second answer (same sheet)	
	Far - Close concurrent report third answer (same sheet)	
	Far - Close concurrent report not answered, WS pairs	
	Far - Close concurrent report not answered, WS odds	



PRO-05
P
Pr
L I C E D C
Far
Close
easy access and highly secure bicycle parking
1
2
3
4
5
26
29
34
36
39
40
41
43
46
48
52
MEX
MEX
MEX
15
5,000
30%
70%
MEX
MEX
MEX
MEX
MEX
15
5,000
30%
70%
MEX
5 min.
10 min.
15 min.
20 min.
25 min.
30 min.
35 min.
40 min.
45 min.
50 min.
55 min.
60 min.
65 min.
70 min.
75 min.
80 min.
1
2
3
4
5

ITEM	Description	Column
	Transcription 'Black' participant	PRO-00 or RCA-00 (Participants' code name)
	Transcription 'Red' participant	
	Transcription 'Blue' participant	
	Transcription Researcher	
	Protocol phase 'Conceptualisation' as designed for protocol	P
	Protocol phase 'Refinement' as designed for protocol	
	Protocol phase 'Definition' as designed for protocol	
	Trophec explorations as designed for protocol	
	Protocol phase 'Conceptualisation' as it took place	Pr
	Protocol phase 'Refinement' as it took place	
	Protocol phase 'Definition' as it took place	
	Trophec explorations as it took place	
	Computer usage - Google images	
	Computer usage - Google web search	
	Computer usage - 3D modelling and render	
	Computer usage - Key note	
	Design process stage participants were working on	L - I - C - E - D - C
	Reading the design brief	
20	Figural representation and number of chronological creation	
	Figural representation's complexity degree (grading 1 to 5 on the bottom of page)	Far ---- Close
	Figural representation's relation to vertical transformations	
	Writing complementing figural representation	
	Writing general comments, reflections and ideas	
	Computer based board	
	Sketches' link, same designer	
	Sketches' link, between different designers	
	Vertical transformation	Far ---- Close
	Lateral transformation	
padlock	Concept ideated	
1	Far - Close concurrent report first answer and working sheet number	
	Far - Close concurrent report second answer (same sheet)	
	Far - Close concurrent report third answer (same sheet)	
	Far - Close concurrent report not answered, WS pairs	
	Far - Close concurrent report not answered, WS odds	


PRO-06
P
Pr
L I C E D C
Far
Close
built-in bike-wheel lock
in wheel device
foldable scooter
helmet-lock
parking system
02
03
11
17
23
30
33
34
35
38
1
2
3
4
MEX
MEX
10
100%
3,650
MEX
MEX
MEX
MEX
10
90%
10%
3,650
MEX
5 min.
10 min.
15 min.
20 min.
25 min.
30 min.
35 min.
40 min.
45 min.
50 min.
55 min.
60 min.
65 min.
70 min.
75 min.
80 min.
1
2
3
4
5

6.7. - PROFESSIONALS TEST SUMMARY

In this case PRO1 and PRO2 functioned as a control group, where the tool was introduced but its use was left entirely optional. In both cases they did not use it arguing that there was either no need, or that it would represent another complication. This reaction was fully expected and supports literature review findings regarding the claim that designers do not take the initiative to incorporate sustainability criteria in the early stages of design, considering the task an assessment to be made later rather than an early aid to build the ideas. Their statements in the interview also support this view. Furthermore, in the case of professional designers it is clear that there are strong constraints coming from clients or, in the case of employees, from management. They do not request it, therefore it is not even considered.

In all cases there seems to be a normal development in the overall test, similar to RCA's test, with the division of the test into three phases appearing to have pushed them to make faster decisions.

Again, just like in RCA's test, there seems to be no direct evidence of any changes in the working process caused by Trophec. There was no fluctuation in the sketch creation, their amount or length of creation, or their level of complexity. There were no distinctive changes in the verbalisations, any fluctuation appearing to be more related to the design stage, e.g. they diminish when reaching the end. In some cases the only change visible is the increase in complexity, which can be seen primarily in the amount of materials and manufacturing processes in Trophec's cycles, but as stated earlier, it is consistent with the nature of the design process. PRO3 made some important realisations about the environmental and social implications of his decisions, but these made no difference to his final design.

This was not the case with PRO4, who after the first exploration noticed that some of the decisions were not compatible with his objectives of recyclability of the product, which made him return to 'far' in his concurrent report - statements in the think aloud also support this. Lastly, PRO4 experienced an interesting reflection about the possibility of mixing product cycles, and how the end of one can represent the beginning of a second. This was stated in working sheet 10, and apparently a consequence of the second exploration with Trophec, where the participant, realising this fact, produced two different cycles combining the concepts he was developing. Some verbalisations from the think aloud also support this.

The influence of Trophec on PRO5 was more direct. He simply wanted a strong material for the structure of his parking system, but when checking the material's characteristics with Trophec, he realised that when the product ended its useful life, concrete, his first choice, was impossible to recycle or reuse, and rapidly came to the conclusion that, with proper maintenance, wood could be as strong and durable as concrete for his application. He also made other decisions, the use of metal, and the ownership of the government that may ensure the dismantling and recycling of the product, avoiding it ending up in landfill.

Lastly, a simple and direct influence was detectable on PRO6: from all the concepts he developed, he chose the one best adapted to the sustainable materials he wanted to use, in this case natural fibres, which eventually led him also to compost the entire product.

From all the designers who used Trophec none of them produced the less sustainable 'add on' solution, and even if there is no direct evidence that linked Trophec to this fact, similarly to the RCA's test, it is arguable that its use may have produced the retrieval of information from the long-term memory. Even if it is not externalised in form of verbalisations, it may create connections between ideas that ultimately lead to this result. A generalised effect of the tool in all designers can not be argued. Nevertheless, there are signs of some positive reactions when exposed to the tool, which is clear would not happen by their own initiative.

6.8. - COMPARATIVE ANALYSIS OF ALL SETS

In figure 6.33 all sets from the three sessions can be seen. In this graphic each point represents one set, the box represents the range and the thicker horizontal line the average. The groups that used Trophec are coloured in purple, and light grey vertical lines separate the tests.

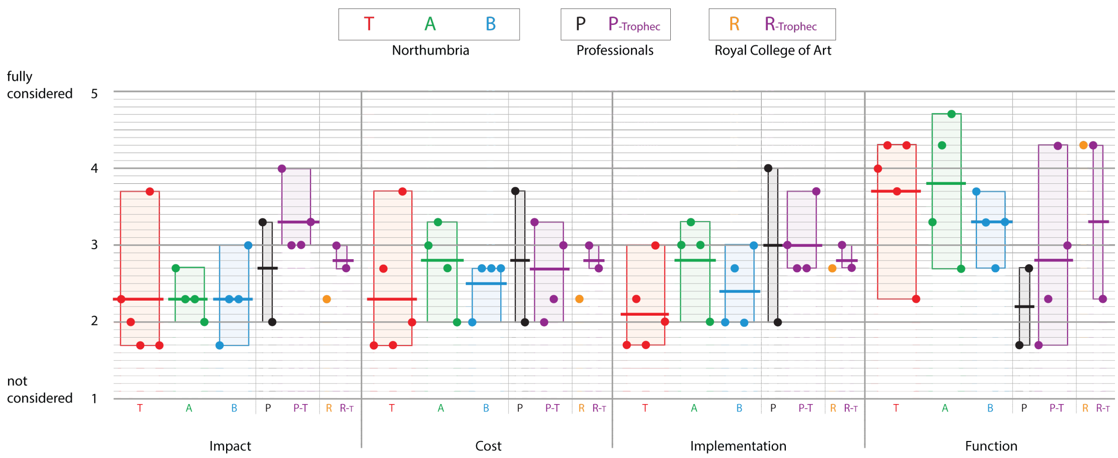


Fig. 6.33 All sets per criteria: environmental impact, cost, implementation and function.

One of the first and most important things to highlight is the identical average of all students in the environmental impact criteria, the average of groups T, A and B in this criteria is two point three, which is the same that RCA1 in colour orange. This probably indicates an overall similar approach to sustainability, in turn possibly caused by the way sustainability is introduced in education. The groups using Trophec, especially the professional designers, scored 25% more on average than the rest in this same criteria. PRO1, which did not use the tool, had a high score in that category, evidently unrelated to Trophec, but supporting the idea that personal interest, awareness and skills can make a large difference, which is not necessarily correlated to the significant difference of the groups using the tool.

Furthermore in the 'cost' criteria all sets present similar results. 'Implementation' interestingly follows the same pattern, with slightly larger differences, and the professionals using Trophec or not, achieved an overall better performance, probably due to their grater experience. It is noticeable how students focus more on 'function' and as consequence received better marks. Professional designers may have searched for more innovative approaches, most of them trying to deter the act, but failing the specific goal of the brief, therefore obtaining lower scores. This was not the case of PRO5 who proposed a parking system and fulfilled the brief's objectives.

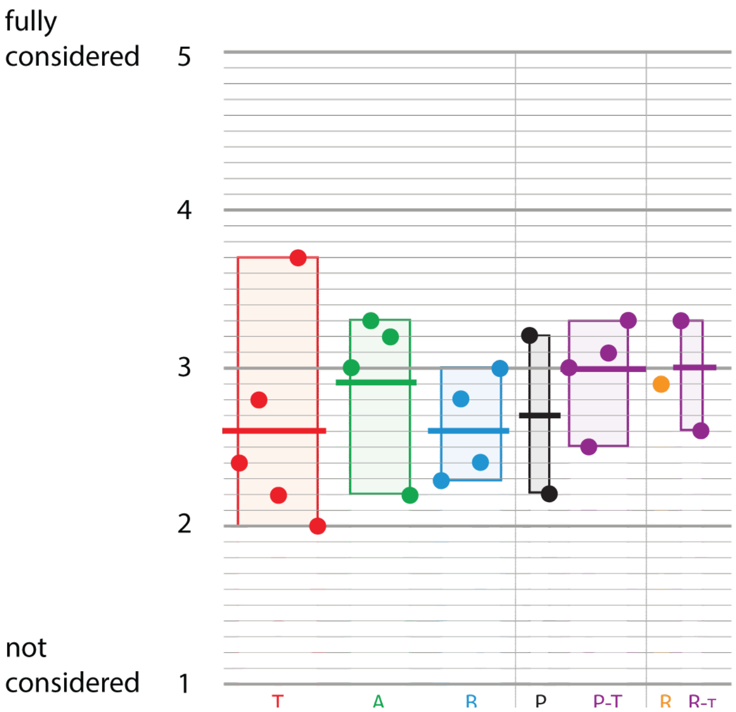


Fig. 6.34 Average per set

In figure 6.34 the average per set of all the brief's criteria was calculated, this graphic attempts to find any difference in the overall scores of all sets. A slight difference can be seen in the groups that used Trophec, but it is negligible, and no relevant conclusions can be drawn from the sets' averages.

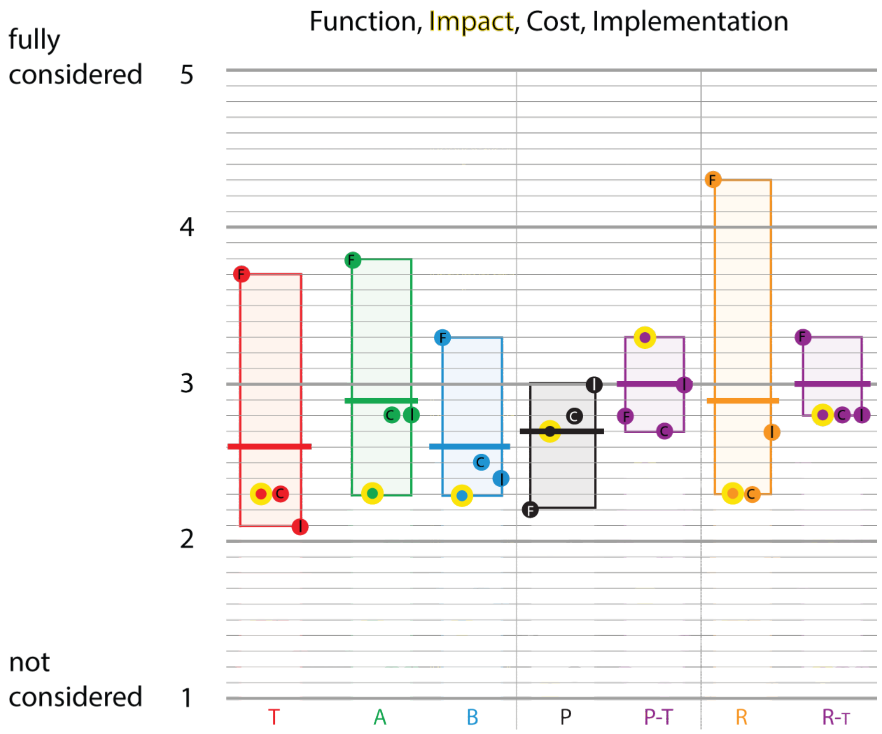


Fig. 6.35 Average per criteria

In figure 6.35 the dots no longer represent each set, but in this case each dot represents one criterion, and the graphic shows the average per criteria achieved by each group, therefore four dots per each group. The first dot in each box represents the 'function' criteria, which is, in the case of all student groups, on top. All student groups have the 'function' several times above the average, and all other criteria below the average; this is consistent even in the student groups that used Trophec (RCA and T). Professional designers show a completely different pattern, 'function' is below average, in the case of the professionals who did not use Trophec (environmental) 'impact' is on the average, and the top score is 'implementation'. For the ones who used Trophec the top score is (environmental) 'impact' and 'cost' is at the bottom. Nevertheless, between the two groups, 'cost' and 'implementation' occupy almost the exact same position. Looking across all (environmental) 'impact' results a pattern is clearly identifiable, all students not using Trophec got exact same result, students using Trophec were half point better. In turn professionals using Trophec were 0.6 points better than the ones not using it, and overall professionals score higher than students. Because of the sample size this study cannot be conclusive, but this is believed to be evidence that makes further research on this area worthwhile undertaking.

6.9. - ONLINE DATA

ALL USERS WITH CYCLES, AGGREGATED DATA

From a total of almost 400 registered users, 94 produced 200 cycles. It is possible that more users completed the creation of cycles, nevertheless, the system does not register the cycle if the user does not save it. The software was available from October 2012, and all data for this analysis was downloaded in January 2014.

The analysis is presented by aggregating data of all the cycles produced. This analysis shows the principal choices designers make when facing these sets of variables, and includes both the users that produced only one cycle and the users with multiple cycles. A detailed analysis of the latter will be presented in the next section of this chapter p.280.

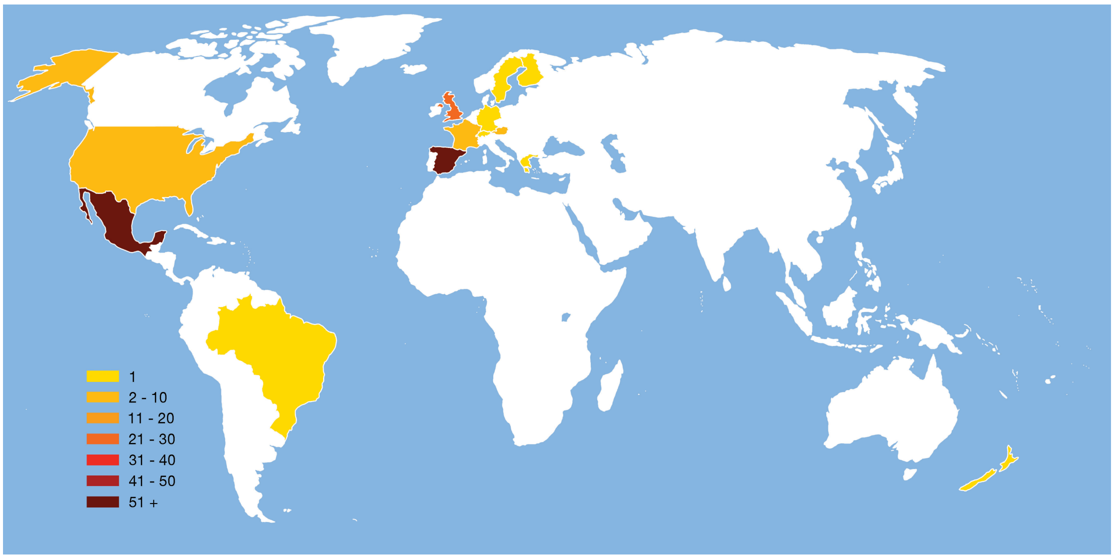


Fig. 6.36 Location of Trophec's active users

The author's attempts to publish the tool in massive design media in order to attract a larger user population as well as more distributed around the world were unsuccessful. Therefore, as can be seen in figure 6.36, the users predominately came from Mexico, Spain and the United Kingdom – the product of the author's personal network.

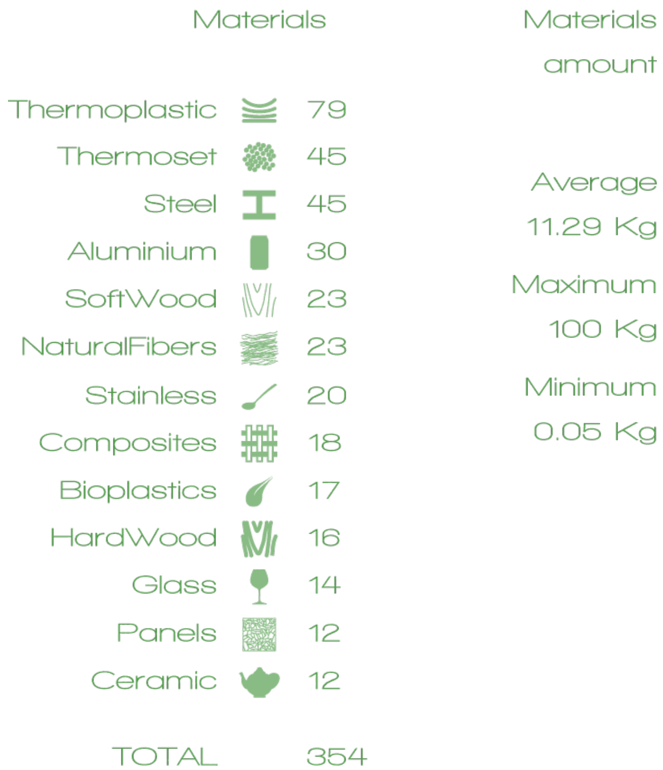


Fig. 6.37 All active users, product's material selection

The first step of the process of creating a cycle is the material selection. Figure 6.37 shows the materials organised by the number of times the users selected them. On top, with 79 selections is thermoplastic, followed by thermoset with significant lower 45 selections, which gives an positive view of the designers' understanding regarding the difference between these two for sustainability matters; equal number of times for steel. It was expected to find ceramic and glass at the bottom of this list, due to its less common use in product design, mostly caused by the characteristics of the manufacturing processes involved. Panels, specified as plywood and MDF, normally intensively used by designers particularly for furniture, surprisingly came almost at the bottom. In 200 cycles, 354 materials were used, with 88 cycles using only one material (44% of all cycles), giving therefore mono-material products, which can be regarded as more sustainable. The range in weight used touches the maximum at both ends, which is a complex factor if it is intended to do a visual comparison of sustainability impact between products as Trophec does; the average was 11.29 kilograms of materials per cycle.

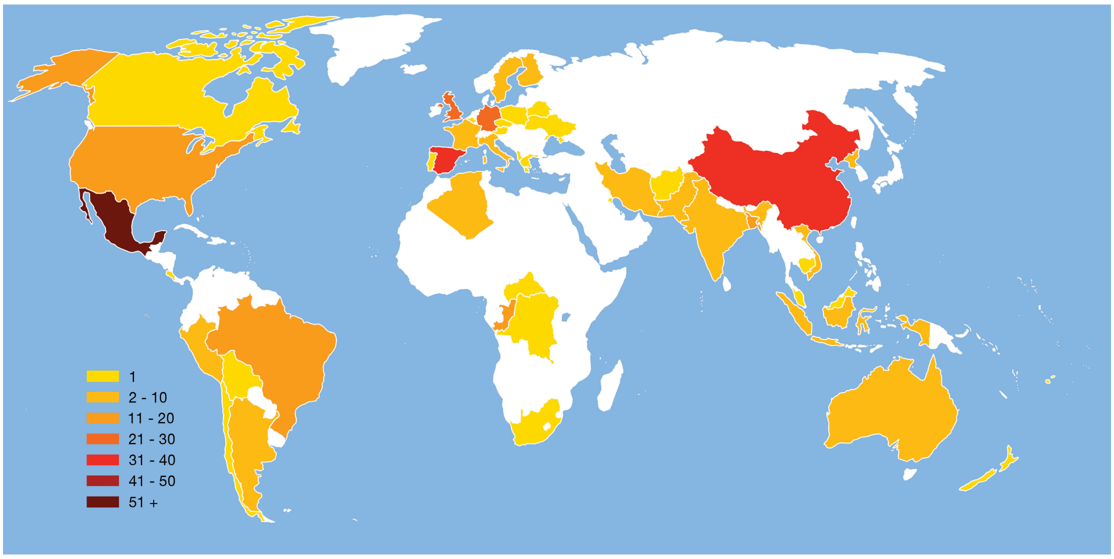


Fig. 6.38 Materials origin

The user is requested to select a country of origin per each material used, the results of which are shown in figure 6.38. The large number of countries from all continents and regions selected is noticeable as it is an apparent desire of 'local' resource of materials from designers that in sustainability terms is normally desired. Also important to highlight is the preference for China and Germany.

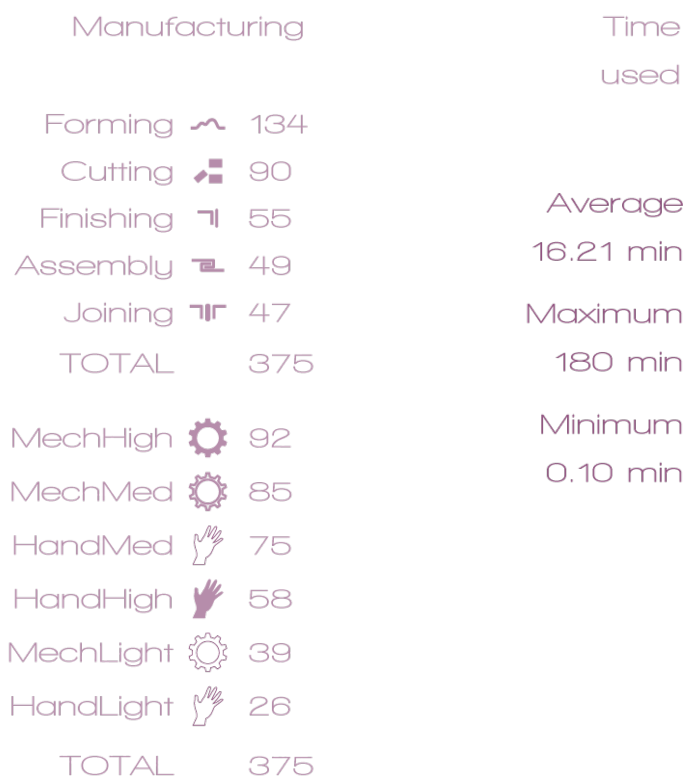


Fig. 6.39 All active users, product's manufacturing processes and intensities

The second step in the creation of a cycle is the manufacturing processes (figure 6.39). In this case a larger number of them were produced, 375 in total, 'forming' being the highest with 134, followed by 'cutting' with 90 selections, and last place for 'joining' with 47. Regarding the intensity of the processes the top place is 'mechanical high', which is the most energy consuming, representing mass production facilities with very large machinery. At the bottom is 'hand light' with only 26 selections; this intensity represents hand-made type of labour. Again the range was used at the maximum possible in both extremes, with an average of 16.21 minutes for all processes. This time 89 cycles had only one manufacturing process, which may be regarded as more sustainable, due to less energy consumption, but can also be considered somewhat unrealistic in terms of producing a finished object with only one manufacturing process.

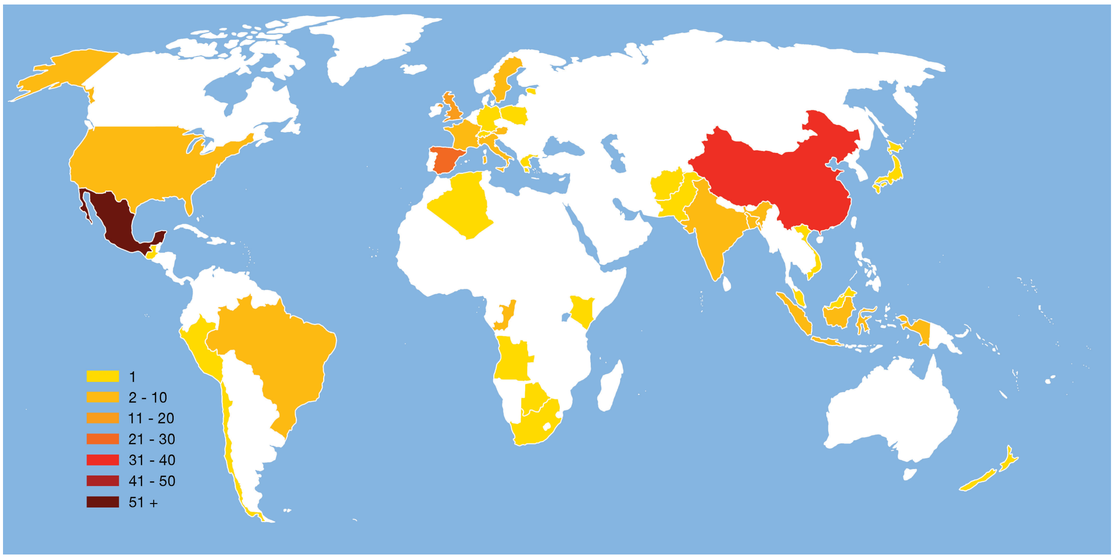


Fig. 6.40 Manufacturing origin

In the country selection on top of the list came Mexico, which related to the users' origin and a high number of local manufacturing. This again could be regarded as more sustainable. However, in second place came China, the expected selection for manufacturing due to lower prices from economies of scale and low cost labour; but also as seen previously with PRO3, as a trustworthy source. Lastly it is noticeable the selection of countries in all continents and regions, which could be product of random selection as designers were just testing the tool, or possible ideas for local manufacturing or diversification, figure 6.40.

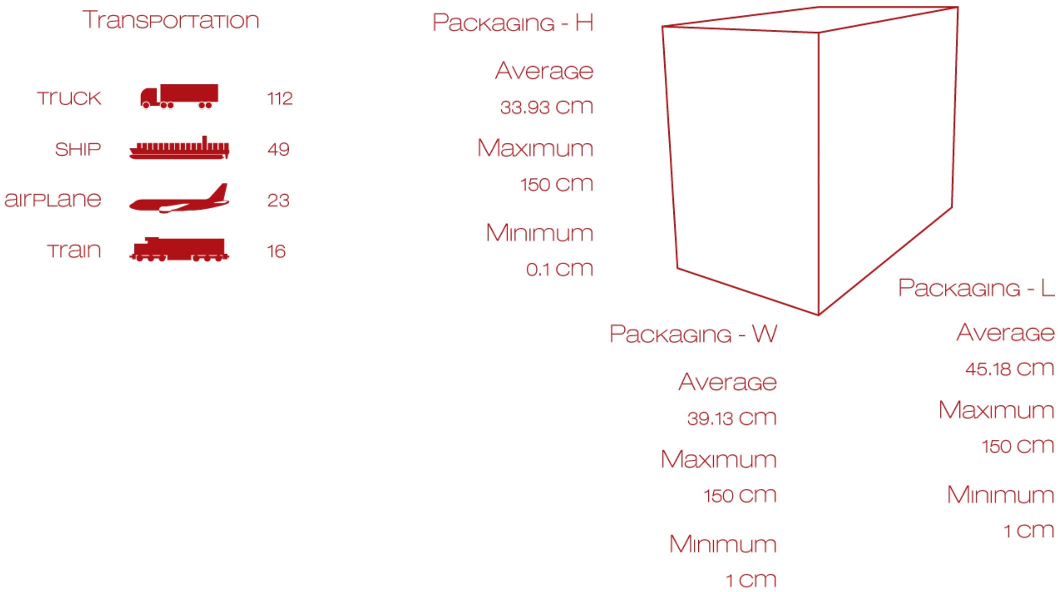


Fig. 6.41 All active users, product's transportation and packaging characteristics

Transportation was dominated by truck with more than double the number of selections with 112 times, followed by ship with only 49 (figure 6.41). The former was the expected selection for local distribution, and the ship for long haul transportation. Understanding the context of the main countries where the users came from (particularly in Mexico where rail transportation is very underdeveloped), it is understandable why train, even if being one of the lowest emitting types of transport, came in last position and truck was first. The size of the packaging ranged again in the maximum in both extremes, with an average of 34cm height by 39cm width by 45cm length.

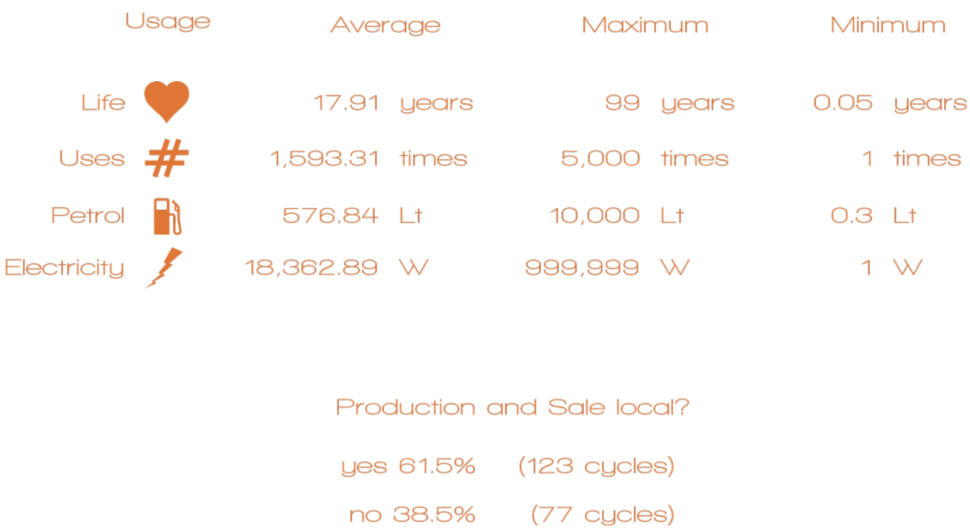


Fig. 6.42 All active users, product's usage characteristics

Life span was unexpectedly high with almost 18 years on average, ranging from 99 years down to 0.05 years. As found in the literature review, the trend is towards shorter life spans, therefore this result could represent a counter action from designers of more desirable sustainable solutions, or again just random selections. The number of uses on average was almost 1,600, figure 6.42. The software had an interface problem with the input of petrol and electricity, it was possible to have zero as amount, but it was necessary to leave the input space empty, if typed zero, the software prompted an error message requesting a minimum of one. This gave as a result many cycles with 'one' in electricity or petrol usage, which probably meant to be zero. In order to highlight and clarify this issue the following charts were produced.

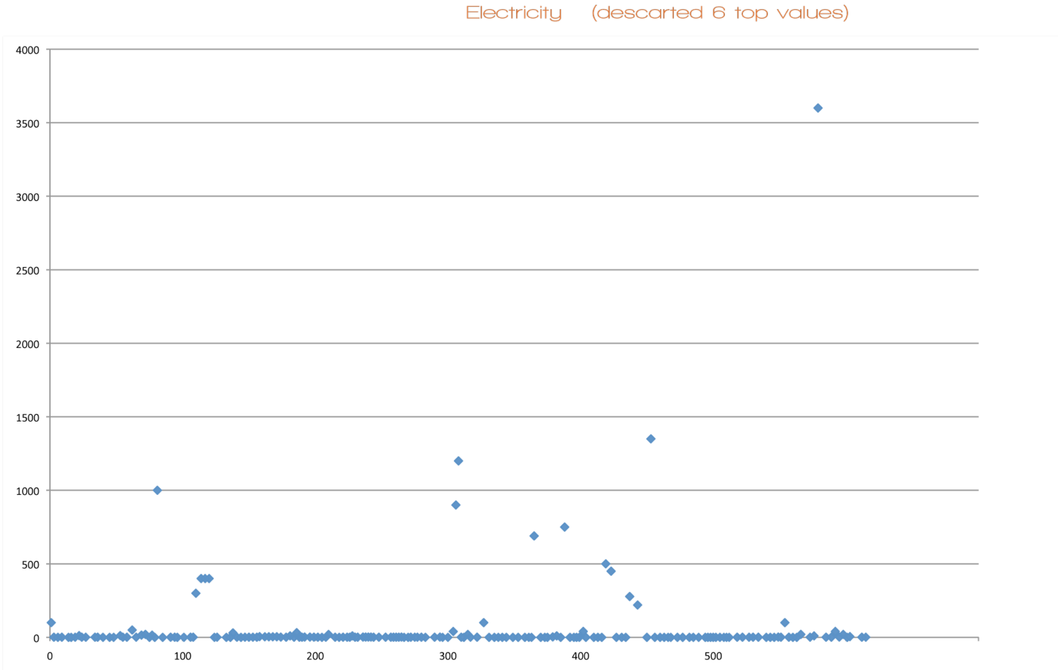


Table 6.18 All active users, electricity consumption

In table 6.18 it can be seen the users selecting one or more for electricity usage, in this case the top 6 values were extremely apart from the rest, therefore discarded in order to show a higher detail in the lower levels. On the vertical axis the amount in watts, the horizontal axis represents the cell position in the excel file from which the data was taken. This chart shows how just a few cycles really made significant use of electricity for the usage of their products. This could be explained by the type of products designers involved in this test more commonly work on, not necessarily conscious decisions of a more sustainable product.

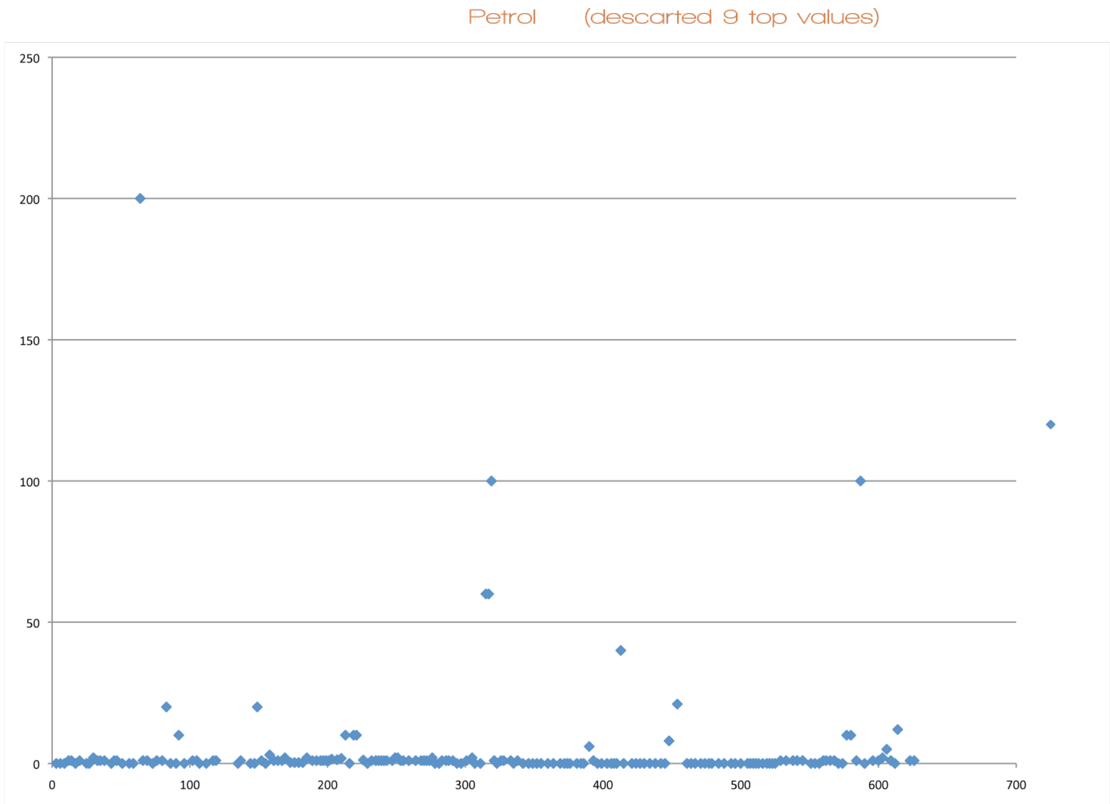


Table 6.19 All active users, petrol consumption

In table 6.19 a similar result to that of electricity usage can be seen, in this case petrol consumption. The top nine values were also discarded in order to show the detail of the lower levels. The vertical axis shows litres, and the horizontal axis represents the cell position in the excel file from which the data was taken.

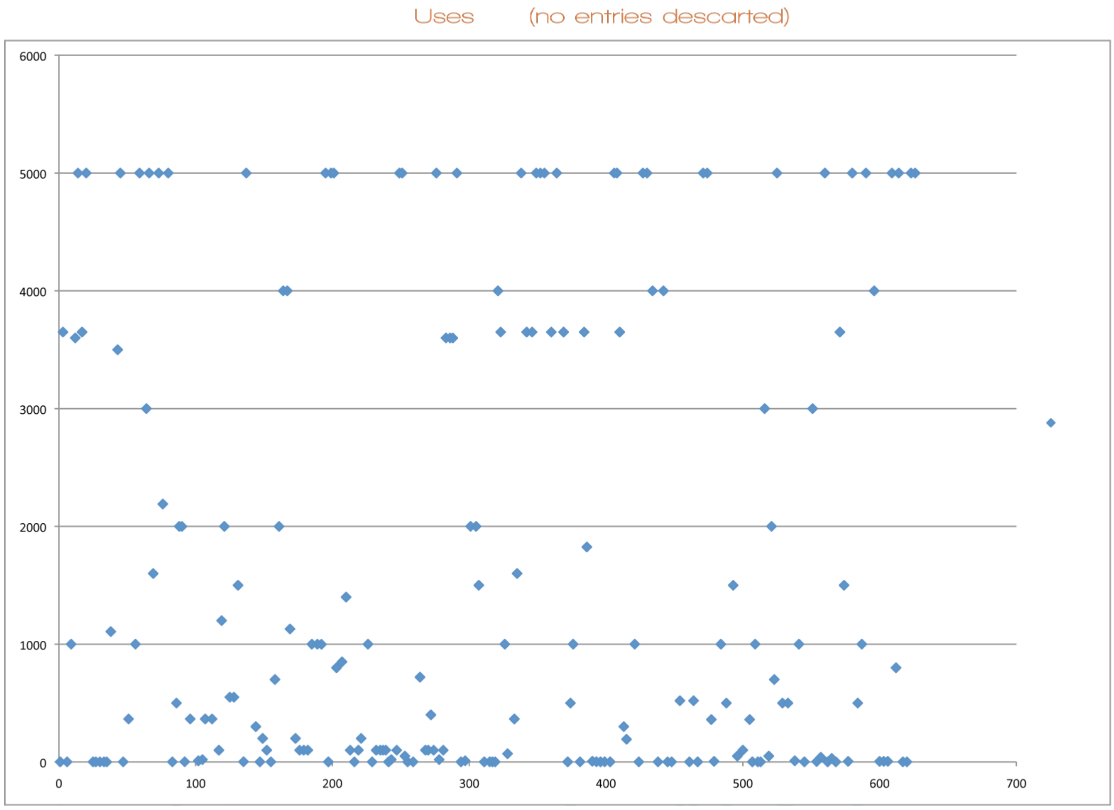


Table 6.20 All active users, product's number of uses

In order to detect any possible pattern, a similar chart was produced for the number of uses (table 6.20). It was interesting to see some coincidences, especially at 3,650 meaning a daily use for a period of ten years, or 1,850 the same rhythm for a period of five years. Lastly an interesting phenomenon was detected - the smaller the figure input the more random the distribution, this will require further study to understand the possible reasons.

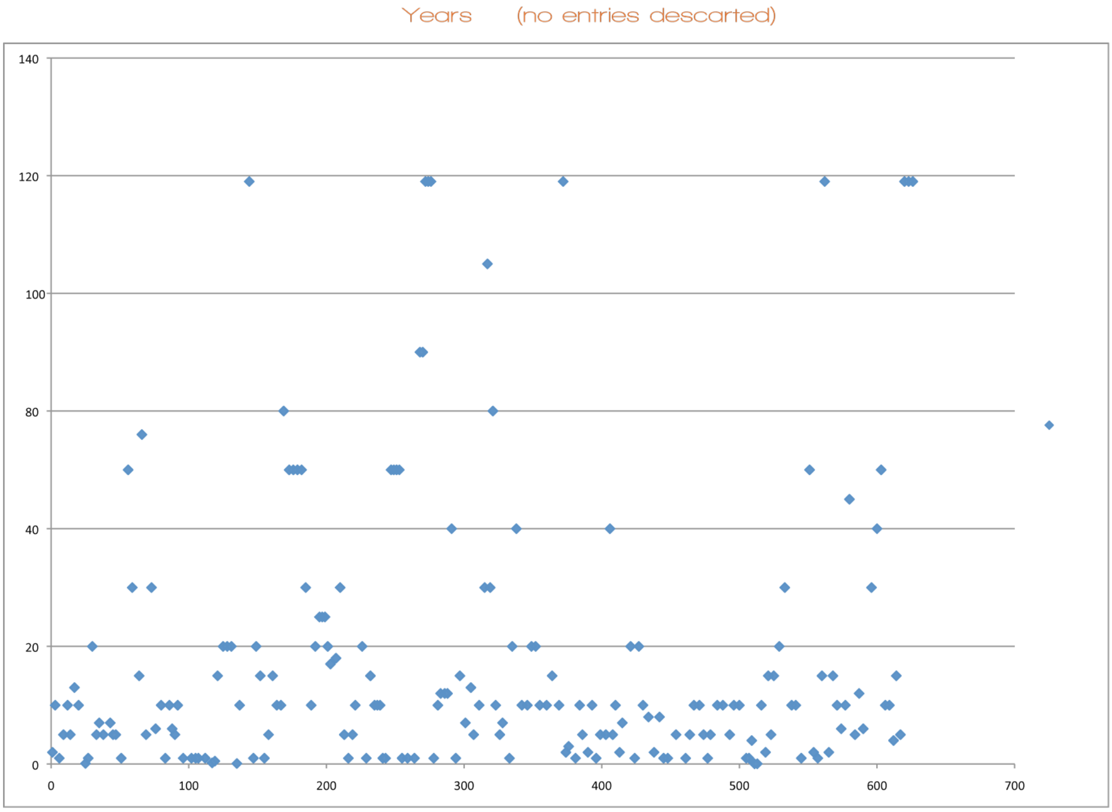


Table 6.21 All active users, product's life span

Similar findings can be seen in table 6.21, where the years of life span are plotted. There are some concurrences in the amounts; the selections normally are values in factors of ten or five years. And as in the previous table, the smaller the number, the more random the distribution.

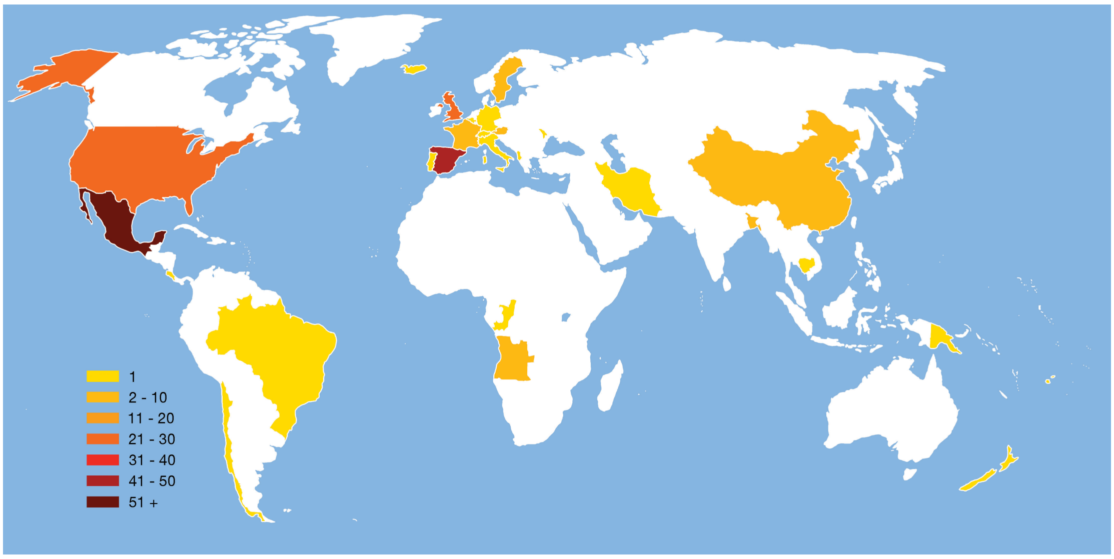


Fig. 6.43 Country of product distribution (sale)

It is noticeable that 61.5% of the cycles had the same country of manufacturing and usage, indicating an interesting inclination for local manufacturing that in sustainability terms is normally desirable, and that 52.5% of the users selected their own country of origin for manufacturing. In figure 6.43 it can be seen how Mexico and Spain are on top, seemingly because of this trend for local manufacturing and sale; followed by the United Kingdom and the United States. The United States has a low number of users, which may show how the USA is seen as a powerful commercialisation site. Interestingly countries like China, Bangladesh, Cambodia, Congo and Brazil, normally seen as sources of materials or manufacturing, were also selected as countries for sale, even if in a very low number.

Usage	Average	Maximum	Minimum
consumers	28.87 %	100 %	0 %
landfill	24.98 %	100 %	0 %
producers	20.57 %	100 %	0 %
compost	17.95 %	100 %	0 %
distributors	7.64 %	100 %	0 %

Fig. 6.44 All active users recycling preferences

The last step of the cycle creation is recycling. It was unexpected to find consumers at the top of the preferences with almost 29% because this will indicate that once the product life cycle finishes the product stays with the owner, demanding therefore interesting characteristics in the design, manufacture and assemble of products. Landfill followed with near 25%, and in third place producers with 20%, figure 6.44, which are the common end of life destinies. More predictable was the last position - distributors with 7%, this because it seems to still be an untapped option: how a product may at least partially be recycled by the distributors, nevertheless this may open interesting opportunities for designers. In all five possible options the range reached the maximums in both extremes.

MULTI-CYCLE USERS

From the previously mentioned 94 users and 200 cycles, 37 of users (39.36%) produced 133 cycles (66.5%). Three users were discarded because one or more of their cycles were the models offered by Trophec as examples. The next set of users with more than one cycle produced will be analysed in the following pages:

- 13 users – 2 cycles
- 11 users – 3 cycles
- 4 users – 4 cycles
- 3 users – 6 cycles
- 2 users – 9 cycles
- 1 user – 10 cycles

For the users with more than one cycle, the objective was to take a closer look at the selections across different cycles and detect any possible trends or patterns. The system saves the cycles in chronological order, therefore an ‘evolution’ in time or changes in designer’s preferences was searched. The software also has a field to type a short message, or as suggested in the videos and webpage, to enter the product title. This permitted in some cases the correlation of the characteristics of the cycle with the product type. For this reason a chart was produced where all cycles could be seen together in order to identify such trends or patterns. Finally it was also decided to only analyse the users with three or more cycles, as it is thought not possible to determine a trend with two cycles.

In appendix G p.320 can be found the charts of the multi-cycle users discussed in the next pages, which show particularly interesting phenomena. Figure 6.45 presents as an example the only user who produced ten cycles (coded Multi-26, the number is a product of the position created in the excel file when data was downloaded from the system, which is automatically determined by the chronological order in which the users entered it).

In a first general approach to identifying trends or patterns, some basic characteristics that could be considered more sustainable practices were analysed: the use of only one material or more, the use of one manufacturing process or more, if the same country was selected in materials source and manufacturing site, if the packaging showed a diminishing in size, if more sustainable transport was used, or if there was an increase in life span or number of uses, diminishing usage of petrol or electricity in product's usage, if better recycling practices were selected and if these were coherent with the material selection.

Half of the users had a preference for using one material only, the same with manufacturing processes, and the same in the country selection for materials source and manufacturing. This may well indicate a superficial selection of variables due to the unrealistic possibility of manufacturing a product with just one material and furthermore with only one manufacturing process. Just seven users showed a clear diminishing in packaging size. Only four improved in their transportation preferences, nevertheless in almost all cases of 'local' manufacturing, the preferred transport was truck. As explained earlier, a larger and more diverse sample will be necessary to consider these trends as a possible improvement in designers' sustainable decisions.

There is little evidence of increase in life span or in product usage. Regarding the recycling selection only five users clearly improved their selection, but it is important to mention that at least fourteen users (66%) had multiple recycling sources, showing an unexpected high level of complexity. This may represent a real interest in designers for a cleaner end of life for their products. Lastly only seven users showed some lack of coherence between their material selection and the recycling scheme they defined.

The name of the cycle stated by the user was highly relevant for this analysis. From 21 users finally analysed, nine of them had all different products, from which the main conclusion is that there is no relevance in apparent trends or the designer's selections if there is not an understanding of the type of product being designed, for which sketches, a final board or information beyond just the cycle is highly desirable. With regard to sustainability, it will always be better to use less material and fewer manufacturing processes or better to use the product for longer and more intensively. However, much more relevant is the possibility of returning all materials used to the 'technical' or 'natural' cycles (McDonough and Braungart 2002). Therefore, special focus has been made in the product type derived from the name stated by the user, and the material selection in relation to the recycling scheme.

From 21 users three were professional designers, all the rest were students from Mexico, Spain and the United Kingdom. The first professional designer (multi-08) used Trophec to analyse three different types of shoes. Thermoset plastics were selected in the first two and coherently 100% of the product ends in the landfill, but in the third (and last created) the main material was bioplastic, and again the selection is 100% landfill. This could be interpreted as an understanding of the impossibility of recycling thermoset plastics and the search for a less pollutant solution, nevertheless it is not coherent for a bioplastic to end in landfill, and probably more understanding of material characteristics is still needed.

Multi-23, the second professional is a researcher from a European University. This user assessed the impact of wood produced in Peru and used in Europe, for this material the user defined 20 years of usage and 100% of recycling in consumers. The other two cycles were a comparison between two aluminium 'cans', both produced locally and with the same recycling selection: 65% to producers and 35% to landfill, the only difference was the transportation means, one truck and the other airplane, any relevant conclusion could be drawn from this user.

The third professional (multi-36) assessed two 'chairs', one made only out of wood, the second one multi-material, the first one 70% recycled by consumers and two years life span, which is not entirely coherent for a material like wood, the second one 60% to compost and seven years life span.

Other relevant findings belong to multi-19. This user assessed three different types of products, each one of them three different times. This was identified by the name of the products, and by adding: 'without' to a second one and 'improved' to a third. In the latter significant changes were made, the selection of bioplastics or steel, instead of thermoset plastics, as well as an improvement in the recycling by removing the use of landfill. Nevertheless, also showing a reduction in the number of uses.

Similar to this last case are users multi 20, 18, 14, 5, 9, 11, 32 and 33, where the same products were analysed. Normally the focus was placed in the material selection and the recycling strategy, and in a small number some improvements can also be seen in the diminishing of packaging size, and increase in uses or life span. In general coherence between material selection and the recycling was noted. Nevertheless, some doubts about how users are interpreting this step have arisen. For example, user multi-9 used 'natural fibres' and recycling 94% by consumers, with an expected end of life for natural fibres as composting. Therefore the issue is whether the consumer is composting or is finding another application for that material.

Understanding these types of decisions will remain speculative if there is no more information about how the designer finally solved the details of the product and ideally how the business model is settled, because as stated by some of the participants, many of these decisions are not actually taken by designers. Defining how the product will be recycled depends as well on the business model, and by the service that may accompany the product, issues rarely proposed by designers as found in literature and interviews.

USER: Multi-26

CYCLE	01	02	03	04	05	06	07	08	09	10
ØRn Thermoplastic	0.2 5	0.3 5	0.3 5	0.3 5	0.4	5				
ØRnRc Thermoset										
Bioplastics							0.2	0.2	0.4	0.3
ØRnRc Composites										
ØRn Steel										
ØRn Stainless										
ØRn Aluminium										
HardWood										
SoftWood										
NaturalFibers										
ØRc Panels										
ØRnRc Ceramic										
ØRn Glass										
	BGD	BGD	BGD	BGD	BGD	BGD	SWE	SWE	SWE	SWE
Forming	×						×	×		
Cutting										
Joining					×				×	
Finishing										
Assembly		×	×	×		×				×
HandLight										
HandMed		5	5	5	5	5			5	5
HandHigh										
MechLight	5									
MechMed							5	5		
MechHigh										
	BGD	BGD	BGD	BGD	BGD	BGD	SWE	SWE	SWE	SWE
TRUCK	×	×	×	×	×	×	×	×	×	×
TRAIN										
SHIP										
AIRPLANE										
PACKAGING	2	2	2	2	2	2	2	2	2	2
PACKAGING	42	28	28	28	85	28	42	42	85	28
PACKAGING	23	19	19	19	43	19	23	23	43	19
Life	50	50	50	50	50	50	70	70	99	99
Uses	200	100	100	100	100	50	100	100	400	100
Petrol	0.3	0.3	0.3	0.3	1	1	1	1	1	1
Electricity	4	4	4	4	2	2	1	1	1	1
	BGD	BGD	BGD	BGD	BGD	BGD	SWE	SWE	SWE	SWE
consumers		25	25	25	25	20	20	20	20	20
distributors							20	20	20	20
producers							20	20	20	20
compost							40	40	40	40
landfill	100	75	75	75	75	80				
name	-	-	-	-	komplement	cover svajs	hanger bagis	hanger bagis	hanger komplement	han

Fig. 6.45 Multi-26, the only user with ten cycles produced.

6.10. - ONLINE USERS SUMMARY

Given that most of the users were students; it is possible to draw the conclusion that the use of the tool was primarily exploratory and its output limited. Nevertheless, some evidence of the understanding of better practices can be seen. Designers may have enough information about what these better practices are, but it is also noted that some issues remain uncertain. The lack of information regarding how the designer solved the details of the product, leaves a blank space where could be argued that there is still the need for specific training for designers. More relevant for this research, is a potential improvement in the soft modelling tool to better aid designers in these first exploratory steps.

6.11. - TROPHEC USAGE ANALYSIS

The video-recorded sessions were reviewed several times in order to obtain the data about sketch creation, verbalisations, etc. One more important source of information could be extracted from it - the detailed timing and performance of designers with Trophec's usage, in both first and second explorations. A short summary of these findings is presented below.

	Materials		Manufacturing		Transport		Usage		Recycling	
	first	second	first	second	first	second	first	second	first	second
PRO 1	X	X	X	X	X	X	X	X	X	X
PRO 2	X	X	X	X	X	X	X	X	X	X
PRO 3	1:39	0:20	1:25 - C	=	0:20	=	1:15 - C	=	0:41	1:05
PRO 4	2:18 - G	0:50 - G	1:47 - G	1:04	0:31	0:15	0:52	0:31	0:56	0:11
PRO 5	2:10 - G	0:45	1:30 - G	3:28 - G	1:53	=	1:30	4:57 - G+C	1:31	=
PRO 6	2:47 - G	1:11 - G	2:02 - G	=	0:54 - G	=	0:52 - G	=	0:37	0:45

Table 6.22 Professional designers Trophec usage timing

In table 6.22 all six professional designers can be seen in the first column, and the corresponding time used for each step of the cycle in the first (grey background) and second exploration (white background). As mentioned before, PRO1 and PRO2 did not use the tool. The time stated in each cell represents the time the user had the popup window opened, and therefore making any selection or glossary consultation. In the cell where a 'G' can be seen, are the moments where the glossary was used, and 'C' stands for the use of calculator, which is not included in the tool, therefore the calculator from the participant's computer or mobile phone was used.

Highlighted in red are the occasions where the usage time increased in that particular step, there is also a green 'equal' sign, which stands for the occasions where the participants did not change anything from the first exploration, therefore did not open the popup window.

A noticeable diminishing in the time used for the second exploration can be seen. This was to be expected due to the natural learning curve of users, and the need to only add some details in the second exploration as a consequence of the also natural increase in complexity of the product.

If the time for each step in the exploration is added, the first exploration ranged from 5:20 minutes for PRO3, up to 8:34 for PRO5. In the second exploration PRO3 used the tool for only 1:25 minutes, PRO6 1:56 minutes, PRO4 2:51 minutes and because of an intensive use of the glossary, PRO5 9:10 minutes. With exception of PRO3 all used the glossary.

	Materials		Manufacturing		Transport		Usage		Recycling		Glossary
	first	second	first	second	first	second	first	second	first	second	
RCA 1	X	X	X	X	X	X	X	X	X	X	X
RCA 2	0:55	1:21	1:34 - G	0:48	1:30	=	0:38	=	2:27 - G+C	0:26	✓
RCA 3	2:46 - G	1:07	1:48	1:20	0:41	1:22	0:58	0:57	0:44	0:42	✓

Table 6.23 Royal College of Art students Trophec usage timing

The same results are seen in the case of students, table 6.23, where on only two occasions was the tool used for longer in the second exploration than in the first. RCA2 total time in the first exploration was 7:04 minutes and in the second exploration 2:35 minutes. RCA3 first exploration was 6:57 minutes and the second one 5:28 minutes. The average of both professional designers and RCA's students give 6:55 minutes for the first exploration and 3:54 minutes for the second.

In summary a cycle can be set up in around five minutes, time which is significantly inferior to other available tools, particularly the ones performing full LCA analysis, one of the key factors why designers do not use them in the early stages of new product development.

6.12. - FINAL PROPOSALS AND TROPHEC

The last section of this analysis makes an observation on the proposals from all participants in order to identify whether the presence of Trophec affects the number of concepts produced and if they were unique or repeated several times. This was done first by identifying all the different concepts generated from all sessions, these can be found in the first column 'Concepts' of table 6.24; 34 different concepts could be identified.

For each concept a red cross identifies the participants who ideated that concept. All sets can be identified on top, starting with the professional designers, next RCA's and finally Northumbria's groups A, B and T. The cells with grey background identify the idea that each participant selected as the final one. Lastly the cells with green background highlight the concepts that were selected as final ones and were 'unique', this means that were ideated by only one participant/set.

The first noticeable thing is the higher number of unique concepts from Northumbria's students. At the bottom of each participant's column, a red number can be found representing the total number of ideas produced. On top of it is a cell displaying whether that participant used Trophec, whether the use of the tool was optional or was not specified when to use it (T-O), or no use was made of Trophec at all.

At the lower end of the graphic can be seen the average number of concepts produced, together with the minimum and maximum, these numbers belong to each session (Professionals, RCA and Northumbria). The range in the number of concepts produced is higher in RCA's test, as well as the average (five point seven), in second position are the professional designers that have an average of four point two concepts, and lastly students from Northumbria with three point three ideas average.

The number between RCA and Northumbria columns stands for the total number of times that concept was produced, the top three with orange background. Lastly, the number between the concept's names and PRO1 column is the total number of times the concept was selected as final proposal; the top four are highlighted with the background in yellow. It is interesting to note that the second concept 'octopus chain' is the only one matching both, more times produced and more times selected as the final proposal.

In summary, Northumbria students had less number of concepts produced but more of them were 'unique' (not produced by any other participant). RCA students produced more number of concepts, but all the final concepts were also produced by other participants, so not 'unique', and professionals are in between. On top of this is the no apparent influence of Trophec in the number or 'uniqueness' of concepts.

x	idea generated
x	idea chosen as final proposal
x	unique final proposals

			T - O		TROPHEC				T-O	TROPHEC			Northumbria test												
													NO TROPHEC								Trophec Optional				
	Concepts		PRO 1	PRO 2	PRO 3	PRO 4	PRO 5	PRO 6	RCA 1	RCA 2	RCA 3		A1	A2	A3	A4	B1	B2	B3	B4	T1	T2	T3	T4	T5
1	Deter, discourage - make it useless to steal (destroy, acid, indelible paint, staining lock, unique)	2	x	x	x	x			x		x	11						x	x	x	x				x
2	Octopus chain/securing several points on bike, 'web' chain/structural	3	x	x					x			9			x	x	x				x			x	x
3	Steel bag - cover the entire bike		x									2									x				
4	Remove part / deiflate tyre/deform frame		x						x		x	7		x					x		x				x
5	Part registration / hidden serial number	1	x			x						2													
6	GPS device	3	x	x	x			x				5							x						
7	Dummy lock (Fake floor lock,	1		x								2						x							
8	Attack black market					x						1													
9	Unattractive	1				x						2		x											
10	Security system (alarm,					x						3				x			x						
11	Builder manual	1				x						1													
12	Home made	1				x						1													
13	Non-passive parking system (ground level, underground, street posts, rooftop)	4					x	x		x		6									x	x	x		
14	Helmet-lock	1						x				2				x									
15	Foldable scooter							x				1													
16	Built-in bike lock (in handlebar, in wheel's hub, in frame, with chain	1						x			x	5						x	x					x	
17	Integrate lock to clothing								x			2													x
18	Retractable chain	2							x			2	x												
19	Collapsible wheel								x		x	4				x	x								
20	Display on wheel								x			1													
21	Free bikes for all								x			1													
22	Uncuttable device									x		2		x											
23	Electrify bike									x		1													
24	Front wheel immobiliser										x	1													
25	Collapsible handlebar	2									x	2												x	
26	Passive parking system (Bulky ring fixing the saddler's tube,	1										1		x											
27	Fire works											1			x										
28	No tension chain' string that 'opens out'	1										1			x										
29	Seat lock (collapsible)											1					x								
30	Locking wheel's spokes device + wire chain	1										1							x						
31	Cable tie (no space to cut)	1										1								x					
32	Bulky bracelets, one for frame, two with cables to secure the wheels	1										1											x		
33	Pedal locks											1												x	
34	Sturdy double bracelet lock	1										1													x
	total number of ideas		6	4	2	7	1	5	8	3	6		1	4	3	4	3	3	6	2	5	1	2	4	5
			T - O		TROPHEC				T-O	TROPHEC			NO TROPHEC								Trophec Optional				
	average				4.2					5.7									3.3						
	minimum - maximum				1 - 7					3 - 8									1 - 6						

Table 6.24 Concepts from all sessions' comparative analysis

Chapter 7 – DISCUSSION OF FINDINGS

7.1 – INTRODUCTION

This research project investigated the incorporation of sustainability criteria in the early stages of design through a novel soft modelling tool called 'Trophec'; the focus of this research at this particular moment of new product development was the result of findings and reflections from the literature review.

Furthermore, previous research has found that the early stage of design is the most appropriate one to incorporate sustainability criteria, due to the feasibility and impact potential to achieve the required systemic innovations (Matzke, Corky Chew et al. 1998, Bhamra, Evans et al. 1999, Ritzen 2000, Sherwin 2000, Lindahl 2005, EuropeanComission 2012). Also, the literature review identified the need for a more specific tool for this stage in the design process that would inform, guide and adapt in a better way to the culture and characteristics of designers in the fuzzy front end of concept development. For this reason a computational online 'soft modelling' (Falk and Miller 1992) tool was developed (Trophec), and employed to assist the investigation phase of this research.

Therefore, a series of tests were executed involving both students (undergraduate and graduate) and professional designers, with both control and experimental sets. The methodological approach focused on using mixed methods in order to detect, by analysing different features of the designer's working process such as verbalisations, external figural representations (sketches), among others, any influences exerted by the tool, and in control groups how designers would engage with sustainability criteria in normal or typical conditions. The main sources of data came from sketches, concurrent and retrospective reports, researcher's observations, and in some cases think-aloud protocol video recordings of the working space, which captured the designer's hands and computer screen. At the end of all the sessions, unstructured interviews were also conducted that produced essential insights. Due to the online nature of the tool and its free access, data was also collected from online users from all over the world.

7.2 - SUSTAINABILITY BASED ON PERSONAL SKILLS, INTEREST AND KNOWLEDGE

One of the first issues to investigate was the predisposition of designers to: take into consideration sustainability criteria in their projects; understand the need to approach sustainability in a more holistic way; and do so in the early stages of design. In this context, 'soft modelling' means offering a low number of variables, and integrating all information in one simple-to-use interactive screen, in order to constantly visualise the entire life cycle of the product, making more evident the 'connections' between different steps of the process. In order to achieve this, it is commonly accepted that precision in the final calculations diminishes. However, in this research it was found that the final impact numbers (CO_2, Kg, or Energy), were not important for the participants in early stages, they rarely mentioned it or commented on it. Rather phenomena like the realisation of the 'connections' and relations between different steps of the life cycle was present in their verbalisations and it is therefore now believed to be an interesting future research area.

In the first test, held at Northumbria University, two control groups and one experimental group showed that even with previous knowledge about the test focus on sustainability; with the tool introduced and tested; and with a design brief specifically requesting consideration of sustainability factors, designers do not voluntarily consider them in their projects. This claim has a diverse set of evidence. Firstly the initial and final survey, which attempted to confront sustainability related issues both before and after the test, showed a random set of responses. This could be interpreted as being highly dependent on personal skills, interest, knowledge, and above all, individual perception of the situation at any particular moment. Another is the number of variables in the design problem and even the physical conditions of the test, which makes the designer's perception to be extremely volatile and diverse. The latter is in line with Goel and Pirolli's (1989) statement that the structure of the design problem is dictated by practice and experience, and the components are not always logically interconnected.

The brief asked designers to address the problem of bicycles being stolen, and stated that 'the winning innovation will be the one that requires the longest time to steal the bike'. There were three other criteria: impact on the environment, cost to buy or implement, and implementation and adoption at scale through commercialisation and other means. Throughout all the sessions it was clearly evident that students focused almost exclusively on the functionality of the proposals, leaving almost all other three criteria as secondary or not even considered. This contradicts Goel's (1995) findings that for early design stages, the focus should be in people, purpose and behaviour, leaving function and structure for later stages of design.

Both students and professionals were aware of the tool, had previously tested it, and were given the option of using it to inform the project, but chose not to use it on any occasion. This is the strongest evidence that under current culture and conditions, sustainability criteria in early stages of design depends on personal skills, interest and knowledge. This is well supported by participants' statements made later in the interviews, where it was declared that sustainability criteria were things to be added 'later', once you have a defined design. This issue raised the idea of including sustainability criteria as an assessment of ideas to be undertaken in later stages of design, rather than being an aid to build them at early stages. As considered in some depth in this thesis, late assessments will mostly produce incremental innovations that would not encourage the level of sustainable development mankind so urgently needs (McDonough and Braungart 2001, Vezzoli and Manzini 2008).

Therefore, it can be said that the design brief has a strong influence on designers' performance, but it is not the only variable, with cultural and contextual factors also playing a part in designers' decision-making. One, in the case of participants working in sets, is the creation of social relations during the test and the inter-relation dynamics. The concurrent and retrospective report helped identify how sets struggled or moved faster in the process; neither of these being correlated with better or worse design proposals. One good example is set RCA3, which had two participants overwhelmingly controlling the developments, with very good dialogue quickly reaching an agreement. This helped them to move faster and reach a more detailed proposal, but one that scored the worst overall mark from that session. In relation to this, and with few exceptions, there seems to be a correlation between sets that produced lateral transformations late in the process and the worst overall results according to the design project grading.

The first test showed no significant differences between experimental and control groups. As a result of the findings discussed above, plus the key need not to depend on personal awareness or interest to incorporate sustainability criteria, the test protocol was modified to include iterations and short periods of analysis and synthesis (Dorst 2003) in which to use the tool.

7.3 - STRUCTURING THE DESIGN PROCESS, ITERATIONS TO INFORM AND REFLECT

For the second and third session, an important change to the test protocol was introduced. The structure of the design process was divided into three steps, where the specific goals of each were related to progressive steps of the design process. Participants where asked to focus on specific goals at each step, and between steps one and two (first Trophec exploration), and two and three (second Trophec exploration), the use of the tool was requested. In order to carry out the test in the most natural conditions possible, the option of creating a cycle or just navigating through the glossary was given. This was considered as a viable option if the participants had not yet generated any product ideas, but undoubtedly the intention was to make them stop for a moment and focus their attention into other sources of information. The investigation in the second and third sessions focussed on finding how this new information, through means of the ‘soft modelling’ tool, affected the designer’s working process.

For the second and third sessions control groups were used again. The first case (RCA1) confirmed the previous mentioned findings of session one, namely that participants were aware of the tool, they tested it before the session (which was not divided in design steps) and in spite of environmental impact being included in the brief’s judging criteria, did not use it (just as in the Northumbria session). The second case of control groups was in the third session, this time with professional designers. The first two designers were also introduced to the tool, they tested it before the session, and between design steps the use of the tool was part of the test, but the use was entirely optional. As expected they did not use it; again supporting the previous discussion.

All other sets and professional designers used the tool as planned, none only used the glossary, all proceeded voluntarily to build a cycle, even if there was no specific product to input in the system. This did not seem to be a problem, with some of them declaring the exercise to be just a great assumption, or just making random guesses, they all finished and in many cases important phenomena were observed.

All major influences detected (mostly in form of verbalisations) happened in the first Trophec exploration (between steps one and two), which is consistent with the idea that early in the design process it is more feasible to include sustainability criteria and the impact of doing so is greater. This issue is also thoroughly discussed in the literature review.

In most cases there was no direct influence of the new information on the embodiment of the object being designed, but there were clear reactions of surprise and realisations from participants of presumably unknown diverse social and environmental facts, these were captured from their verbalisations. This could have lead to the retrieval of information from the long-term memory, which ultimately may have driven participants to produce more sustainable solutions. Nevertheless, the sample tested is too small and does not provide enough evidence to support this.

The main clear influences happened with professional designers. Overall they obtained a more balanced grading than the students, which as mentioned previously, focused primarily on functionality. When analysing the average scores of all sessions, an interesting pattern emerges: students focused on functionality and all other criteria are noticeably below average, including RCA sets using Trophec. Professionals using Trophec had as top score ‘impact on environment’, the two that did not use it had ‘implementation’ as top mark. ‘Cost’ and ‘implementation’ in both had almost the exact same position whilst ‘function’ fell below average in both. The type of solution professionals created could explain this last point. As mentioned previously, the brief stated that ‘the winning innovation will be the one that requires the longest time to steal the bike’, and interestingly the professionals focused more in deterring the act, and many of their solutions did not intended to stop the thief at all, therefore, not satisfying the brief requirements but going beyond the immediate need in order to solve a higher degree problem. It could be argued that the test and the tool had a deeper influence on the professionals, and their score in ‘impact’ was by far greater than all other sets (figure 6.35 page 266). This may also have wider implications relating to design education, and how sustainability is perceived and taught, however this lies outside the scope of this study.

Simpler but clearer influences were detected through the verbalisations of the think-aloud. Before the first exploration with Trophec, PRO4 had already envisioned some recycling strategies specially developed as part of his product’s life cycle. When checking the materials’ characteristics he realised the impossibility of his assumptions, as is clearly demonstrated in his statement: ‘because of ignorance, what you do here is not necessarily the best option’. This is further supported in the concurrent report, as before this had happened the participant stated being one step closer of reaching the final solution, once this realisation took place, he returned to the previous step and stated: ‘I feel farther than at the beginning’. The experience of these ‘connections’ within a cycle, made PRO4 also get into a profound reflection about the possibility of combining the life cycle of diverse products, which ultimately led him to produce two cycles in the second exploration.

PRO5 had a similar experience. Before the first exploration he had a well-developed idea, which included some materials selection, one of them using concrete for the base of his parking system. When analysing the material characteristic with Trophec, and under the notion that he had to specify how the product’s life would end, he realised that concrete is not recyclable or reusable, and therefore decided to change material and came to the conclusion that wood, with proper maintenance, could be as strong for his application and last as long as concrete. This change did not affect the design embodiment he was working on; the form and function remained exactly the same.

Lastly PRO6 developed several concepts in the first step of the test. Proceeding with the first exploration with Trophec, he consulted the materials’ characteristics and settled on a recycling strategy. When starting the second step of the design process, he stated that the tool ‘gave him a lot’ in order to focus his work, and proceeded to select one of his existing concepts and worked on it for the reminder of the test, declaring that it was the one best fitting his sustainability target.

The analysis of these influences started with the uncertainty about how the use of such a tool would affect the working process of designers, therefore a mixed methods approach was used. It could be stated that there seem to be no influences directly related to the tool in any of the analysed elements of the working process: sketches do not change in quantity, time of creation, or even connections between them. Dialogue also continued in amount and rhythm; no relation has been seen with the appearance of lateral transformations or new concept creations. All influences were detected in participants' verbalisations when clear broad decisions and reflections were being made. This also led to the conclusion that there was no need for a deeper analysis of the think aloud protocol with a coding method.

One unexpected phenomena was observed. When the flow charts that visualised all the data sources were finished, a comparison of all participants made evident three distinguishable patterns: PRO1 and PRO6, both working as employees in large companies, had the same type of lateral and vertical transformations, many independent ideas early on the process, before selecting one of them, which was developed during the rest of the test. It is also noticeable that these two participants received the highest scores in the design project grading. PRO2 and PRO4, both working as independent consultants, also matched in the pattern of lateral transformations and new concept development, with many ideas being developed through complex lateral transformations within the first third of the test. Later both developed four correlated ideas all the way to the end, none of them chose only one, and these two participants received the lowest scores in the design project grading. Lastly, PRO3 and PRO5, the former a designer-entrepreneur and the latter a designer-stylist, both had the same pattern: only one concept very early on, which was developed during the rest of the test. They also received very similar scores in the design project grading, and both are mid-table. This phenomenon seems to be unrelated to the use of the tool, and even if highly interesting, is not within the scope of this study. A larger sample would be needed to further correlate and ensure results. Nevertheless, this remains an interesting topic for future research, for example to investigate for any correlation with Bar-Eli's (2013) strategies.

This phenomenon was detected thanks to the visualisation of the process in the flow charts developed in this research. This visualisation method proved to be highly useful in relating different elements of the working process. Due to the scope of this research no further analysis has been conducted, but it is believed that this visualisation method could produce other relevant insights in the analysis of the design process, and thought to be one important contribution from this research.

7.4 - REACTIONS FROM PRACTITIONERS

The opportunity of having several professional designers involved with this research was maximised by ending the sessions with an unstructured interview. The principal questions addressed the conditions they faced in practice when dealing with the incorporation of sustainability criteria in their projects. The responses were enlightening; PRO1 and PRO2, for whom the use of Trophec was optional and who decided not to use it, also made comments relating to the perception of sustainability as something to add later (just like RCA students), supporting the idea that all designers, not only students, see the incorporation of sustainability factors as an assessment to perform late in the process, rather than an early aid to build the concepts.

Beyond that, the most powerful declarations related to the fact that many decisions affecting the design are not taken by designers at all, with the design brief normally made by management or marketing departments. Some decisions that could make the product more sustainable are related to the business model, in which, almost all designers agreed they have no input, in line with findings of research discussed in the literature review (Sherwin 2000, Baynes 2001, Lee-Mortimer and Short 2009, Deutz, McGuire et al. 2013, Stevenson 2013). The only exception came from PRO3 and PRO4, who have been involved with start-ups, and who declared that in the case of small new business, they do have the chance to intervene, but experienced entrepreneurs rarely have that level of access.

Furthermore, they accepted that they do not think of sustainability because there is no demand; their clients or employers normally see sustainability as extra cost and extra time, and do not request it. Lastly, many of them agree that companies' processes are divided across different departments, designers rarely get the chance to influence them, and these departments are almost never connected. Companies tend to work in silos defined by the company structure and there is no one, not even in management, who has the vision or control of the entire process. Therefore, the realm of action of designers is greatly limited. Sustainability, some of them declared, must start within the company's culture. These findings also supporting the previous work of Johansson (2002) and Bhamra & Lofthouse (2007), just to mention a few.

The above also supports the analysis in the literature review, in which the macro-economic model and in many cases even society, is the driving force for the culture and performance of companies, ultimately dictating what is commonly requested and expected from designers.

One last outstanding opportunity for this research took place while writing this document. Dr. Chris Sherwin, whose work has been cited previously, was contacted and agreed to be interviewed, and granted permission to be mentioned in this analysis. Dr. Sherwin holds the position of Head of Sustainability at the internationally-recognized design consultancy, Seymourpowell. The research mentioned in this document is his PhD thesis, completed in 2000, where he makes a number of fundamental findings related to eco-design and its practical application by professionals. Dr. Sherwin mentioned that today almost half his work is dedicated to 'demand-creation', trying to get clients to write sustainability into projects. This is not always successful, and depends on whether there is a corporate sustainability mandate or a strong business case.

Dr. Sherwin (2000) found that eco-design was *'not connected to design at all'*, it was reduced to just *'technical dimensions'*. Furthermore, recognising the limited capacity of designers to influence all the design process, he stated that design should *'stretch and extend their own competencies'*. When asked about the advances achieved in these last 14 years in this area, he said that designers definitely *'are not at the leading edge of sustainability'*, that even if some progress has been made, it is dominated by *'creeping incrementalism'* and *'business-as-usual'*. He sees only two exceptions: the *'clean tech movement'* (renewable energy, green chemistry, eco-transport options etc. in which designers are not involved), and *'social innovation'*, where *'entrepreneurs work outside the formal structures/drivers of capitalist economies'* where designers have had some important successes. Nevertheless, he adds that *'consumers won't drive the sustainability revolution'*, and closes by saying: *'We need to extend our approaches from only focussing on the 'consumer/customer journey' and touchpoints, to all the aspects of the 'product journey', both upstream issues like sourcing, transport and manufacturing, and downstream issues like disposal, recycling and reuse. I don't think we are anywhere near training designers to do that and I still see lots of designers thinking they can deliver sustainability successfully with these old-fashioned human-centred design processes. We won't.'*

The findings of this research project sadly show that little advance has been made in the last 14 years. The focus of whole systems design, which could finally provide the 'integration' of the *'product journey'*, is still young and requires much more effort (Charnley and Lemon 2010). Furthermore, it provides a foundation to state that the influences of Trophec on the working processes of designers were mainly related to this 'technical dimension'. Nevertheless, because of its focus on the early stages of product development, 'soft modelling' could be seen as an opportunity to assist in such integration.

7.5 - ONLINE USERS AND AGGREGATED DESIGNERS' PREFERENCES

The 'soft modelling' tool was developed as an online application, enabling the opportunity to test it and gather data beyond the sessions described. Users from all over the world had access to the tool, and even if the total number of users did not reach the large number initially planned, it did collect a substantial amount of data, the product of 94 active users, creating a total of 200 cycles.

Two different types of analysis were made, firstly an analysis of all users and all cycles produced, which gave a picture of designers' main preferences. Some things were expected, like the preference for plastic above other materials like metals or wood, or the use of energy-intensive manufacturing processes above hand-made or low energy-intensive.

Also noticeable however was the high percentage of users indicating use of local materials and local manufacturing, despite the expected results of China as a common source of manufacturing or the USA for sale. Also discernible was the apparent interest in experimenting with complex and diverse recycling strategies, which may be indicative that the knowledge of and interest in sustainable practices in some cases may exist. It is evident that designers engaging with the tool have inherently an interest or curiosity for sustainable practices, but as mentioned above, the context could prove to be a great deterrent for the further application of such knowledge.

Nevertheless, this type of data provides a limited vision of designers' activity. In order to fully understand what the data from these cycles means, it is essential to see how their selections are turned into real products and services. It is particularly important to see how the recycling strategies are resolved since, as mentioned previously, many of the decisions are taken not by designers, and it is important to differentiate the 'ideal' situations from the real possibilities.

The second type of analysis was made of users with more than two cycles (in total 21 users and 133 cycles), in which the interest was to identify trends or patterns. Due to the fact that the system saves the cycles chronologically, an evolution or changes in preferences could have been expected.

The analysis of the multi-cycle users gave as a primary insight their focus on material selection and recycling strategies as the principal factors of experimentation. This demonstrates the need to promote more intensively other types of strategies like longer life span or more intensive use. But just like in the general online data analysis, there is the need to correlate this data with the details of how designers solve the actual product design, and if this is achievable in real business conditions.

7.6 - TROPHEC AND DESIGNERS' PERFORMANCE

The main factors found in literature relating to the reluctance of designers to use the eco-design tools in early stages of design included their complexity level, their time consuming nature and in many cases the need for special training. As part of the analysis of this research, the length of time that participants used the 'soft modelling' tool was measured in order to provide a reference point and to assess if the tool's complexity was appropriate at least for the time usage point of view. For the first exploration the average time for both students and professionals was 6:55 minutes and for the second exploration 3:54 minutes. This is coherent with the notion of a learning curve; the more the participant uses the tool the faster and more efficient it becomes. It also correlates with the fact that the complexity level of the product being designed increases as it moves along the design process, and the use of the tool changes from exploratory to just adding features to an already defined object. Lastly, it also correlates with the idea that incorporating sustainability factors is more appropriate, and has greater impact, early in the design process.

The recorded periods could also show that once the user is familiar with the tool, no more than two or three minutes will be required to set up a cycle. As discussed previously, the focus should not be on the final numbers of the impact (because in a 'soft modelling' tool they are just indicative), the focus should be on highlighting and evidencing the connections within the cycle and the impossibilities or implications of certain decisions.

Lastly, an empirical analysis was made of the concepts proposed in relation to the amount produced, and if they were also produced by other participants or were 'unique'. This showed that: the undergraduate students from Northumbria produced fewer concepts but they were more 'unique'; graduate students from the Royal College of Art produced a larger number of concepts but were not unique at all; and professional designers are in between. But more important for this research, there seems to be no influence of Trophec in the number of concepts produced.

Chapter 8 - CONCLUSIONS AND CONTRIBUTION TO KNOWLEDGE

8.1. - INTRODUCTION

The final chapter will review the key findings in relation to the research objectives and questions raised in chapter one in order to reach overall conclusions, which will lead the reader to the discussion of the primary contributions of this study and the limitations identified. Finally, it will close with a discussion of the possible lines for future research.

8.2. - OVERALL CONCLUSIONS AND SUMMARY OF KEY FINDINGS AND CONTRIBUTIONS

This research proposed as a main question:
How are the designers' working processes influenced or altered when sustainability-related information is presented in early stages of new product development, through means of an online 'soft modelling' software (Trophec)?

The working processes, in terms of the production of external representations (a flow of sketches and verbalisations) **did not seem to be affected at all**. The principal reactions from designers seemed to occur in specially allocated reflective moments directly related to the use of Trophec, ultimately informing the designer of sustainability factors. In some cases, designers reacted in order to achieve more sustainable solutions based on the information provided by the software. Nevertheless, the reflective moments to use the tool do not take place if they are not planned into the design process. Designers generally do not include sustainability criteria in their projects voluntarily, which supports the findings from the literature review, which among other reasons, are the result of the lack of demand for sustainability initiatives from clients and employers as "external" reasons, and lack of motivation or awareness among others as "internal" to the designer's realm of action (Stevenson 2013). Furthermore, this lack of interest may also have the possible consequence of driving a deficient education on sustainable design.

This research also produced the next sub-questions, to which the following responses are provided:

RQ1: *Is 'soft modelling' a meaningful way of presenting sustainability information to designers at early stages of a new product development?*

The tool developed for this research did not achieve the desired level of development necessary to confidently respond this question, as it will be explained in chapter nine p.300 of this document. But due to certain phenomena described in chapter five and six, it is believed that some characteristics of the soft modelling approach (like the use of simple graphics and concentrating on 'visual' communication, the use of only one display, and the use of colour coding for each step of the life cycle), might be an effective strategy for early stages of design. Nevertheless, important improvements to the tool are necessary.

RQ2: *As an eco-design tool, when is the software being used?*
If left as optional, **designers do not use it**. Incorporating sustainability criteria is seen as an activity to be performed after the idea is defined, and is seen as an assessment, rather than an aid to create concepts with aspects of sustainability embedded into the product, which supports the literature review findings. Therefore, it is necessary to include pre-established periods for its use and reflection, that in the case of Trophec can be as short as two or three minutes once the user has become familiarised with the tool. The timeframe where the tool had more significant influence was as early as conceptualisation, even if no idea had yet been defined.

RQ3: *As a way of identifying the progression of the design process, are the creation of sketches or any other external representation altered by the use of the tool?*
Sketches show no evidence of having been influenced by the tool; they simply captured the progress of the different working processes. Sketches were analysed in detail together with other external representations in order to capture any possible type of disruption in the working processes, as explained in chapter 6 p.202. Therefore, a mixed methods approach was used: the concurrent report together with the think aloud verbalisations were the only methods that clearly detected some influence of the tool.

RQ4: *Did the presence of the 'soft modelling' tool, and its information help designers envisage sustainable solutions?*
When facing broad decisions in the early stages of design, **the tool provoked reflections that in some cases led to improvements designers' concepts in terms of sustainability** - mainly in material selection, and the realisation of the 'connections' between different steps of the life cycle, this was particular of two professional designers as discussed in chapter six sections 6.6 p.238 and 6.7 p.263. As mentioned previously these reflections happened only when time was allocated for it, not by designers' own accord. It is recognised that the tool still is not fully suited to be used in early stages, several limitations where identified, which are discussed further in chapter nine p.301.

Nevertheless, it also raised important issues about the real capability of designers to influence all factors of the product design, many of these belonging to other professionals including management or marketing. Therefore, integration between different departments within a company may be a significant topic for future research.

RQ5: *If RQ4 is positive, could it be argued that an increase in the speed of identifying sustainability factors took place?*
An increase in speed cannot be argued but evidence of the tool's efficiency could be. If the time to use the tool and reflection is not allocated, sustainability considerations are normally not made. Only when allowing these periods, the identification of sustainability factors may take place. In the literature review was found that one important deterrent for the use of Eco-design tools is the time that is required for its use, Trophec showed that an important reduction in time might be possible.

As a result of the previous, a summary of contributions and findings is presented next.

8.3. - CONTRIBUTION TO KNOWLEDGE

The tool did not provoke a constant and generalised influence in the incorporation of sustainability criteria, believed to be mainly caused by certain limitations of the tool, which will be further explained in chapter nine. Therefore, the main contribution presented next is the method used to capture and analyse the design process, which it is believed can be applied for other purposes. Other contributions are related to the evidence found regarding the apparent conditions that could potentially lead to a more robust result and clear influence of a tool for early stages of design.

- **The design process visualisation technique and analysis method provides a contribution to design research methodology.** The flow charts developed for this research organise, and present data from multiple sources in a novel way, combined in a purely visual manner, which allows the researcher, through pattern recognition, to connect and highlight different aspects of the designer's working process, and the possible discovery of new phenomena.

- **Establishing short periods for analysis and reflection during the concept generation phase enables relevant (sustainability) information to be considered through engagement with the tool**; designers will tend to see the use of the tool as an assessment to do at the end of the process, instead of framing creative opportunities at the beginning. It was observed that no influence would take place if pre-established time for its use and reflection were not allocated, designers don't do it on their own accord, which supports the literature review findings, chapter two section 2.5 p.43. These periods can be as short as two or three minutes once the user is familiar with the tool, which fulfils one of the requests of designers of not being time-consuming. Furthermore, these periods should not be seen as an assessment, but as explorations intended to build awareness and allow designers regain a more integrated approach, and doing so coherently with designers' needs and culture in the early stages of new product development.

- The only evidence found that can be directly related to the use of the tool was **found in verbalisations within these periods of reflection**, therefore, the think aloud method appears to be the best method to use when analysing tools for the early stages of design. Influences such as the reflection in material selection or the realisation of the connections between different steps of the life cycle that may evince more sustainable solutions, could indicate that designers may have the knowledge but applying it is not a normal practise, which supports the findings in the literature review related to external factors deterring designers to integrate sustainability criteria, factors such as lack of client's request or market demand amongst others.
- **Visualising the entire life cycle and highlighting the connections between the different steps**, as well as allowing focus on the particular without losing a systemic perspective **could potentially create important insights for designers**, which may ultimately lead to more informed decisions.

8.4. - FINDINGS

- Designers perceive sustainability as optional, as an 'add on' for later stages, which supports the findings in the literature review, and adding to it the interview with Dr. Sherwin, highlights the little or no change in designers' perception in at least the last 15 years, and at the same time raising questions about design education for sustainability. It is therefore proposed as necessary to change the perception of sustainability factors to be considered as nomological[1] constrains.
- The context of professional practice can limit designers' realm of action, as well as the perception of their own intervention capabilities. Supporting findings in the literature review regarding the existence of business and social norms that predispose designers to act below their potential; with many of the decisions affecting a product's sustainability being taken prior to the designer's intervention. Companies' structures distinguish isolated departments that tend to operate in 'silos', and there is often no one providing an overview of the entire process, highlighting the above-mentioned connections. It is therefore equally proposed as

[1] Dictated by natural law, 'hard' non-negotiable.

necessary to change the perception of sustainability factors in the larger context of industry to be considered as nomological constraints.

- The early stage of design is a very rapid, ambiguous and personal process. Verbal and non-verbal external representations are essential to its analysis, and therefore video and audio recording is highly efficient and recommended.
- The tool's influences were detected in the first allocated time for its use, never in the second, which supports the idea that the earlier the intervention the easier the implementation.

8.5. - LIMITATIONS OF THE STUDY AND FUTURE AREAS OF RESEARCH

The intrinsic characteristics of the design process make it challenging to draw generalised conclusions. For some of the insights achieved in this research, larger samples would produce more robust results. One important limitation was the development of the tool itself, which will be discussed in detail in the next chapter, but that due to time and resources constraints did not achieved the ideal level of performance. Lastly is the access to designers willing to participate in research, especially professional designers, and within this the possibility of testing the tool in 'real-life' conditions: in longer and more complex projects, in the interaction with other professionals and with emergent situations.

Other interesting phenomena detected, outside the scope of this research, were reported because of their potential to help understand the designers' working processes and characteristics, but remain as an observation and future area of research.

Throughout the course of this study important lessons were learned in relation to the methods of investigation, and their effectiveness for the specific goals of the research. Concurrent and retrospective reports, as well as sketch analysis provided important information about the designers' working processes but there seems to be no relevant relationship to the use of a 'soft modelling' tool, therefore the focus should be on the verbalisations of the think aloud protocol as the main way to obtain information about the designer's cognitive process, his/her reflections, analysis and decisions. Important to mention is that in early stages of design, designers did not seem to voluntarily allow short times to reflect with the use of the soft modelling tool.

Besides some improvements to the soft modelling tool, which will be discussed in the next chapter, it is highlighted the importance of the simplicity of the information delivery and demonstrating the connections between the life cycle steps. Even more interestingly, the possibility of proposing a version of the soft modelling for other professionals, in order to investigate the discussed participation of other departments within a company in the full design process. Performing similar tests with multidisciplinary teams, ideally within a company, could provide further valuable insights in the pursuit of more sustainable product development.

As a collateral outcome of this project, an interesting area of research could lie in the visualisation of the design process produced in the flow charts. The interesting correlations between similar professionals and their lateral transformations and new concept creation, together with sketch creation, verbalisations, etc. could produce further insights into the general knowledge of the working processes of designers.

8.6 - FINAL REFLECTIONS AND IMPLICATIONS

The process of this research presented many challenges in different levels: personal, professional and intellectual. Humans can change their context in an extremely complex way, making this a perennial and sustained process is a task beyond any person's or profession's reach. We may have enough knowledge and technical capacity, but it seems that there is still work to do in the integration of solutions and in the exploitation of each profession's characteristics and skills working in combination. Our capacity for questioning our strongest and oldest structures, as well as our assumptions is essential to innovate, and make human interactions with our environment, a truly sustainable process.

Designers are active part of this process, and this research has attempted to show how they, assisted by the use of a soft modelling tool in early stages of design, could contribute with important improvements. However, constrains in the time and resources of this research did not allow the tool to reach the desired level of development and obtain more robust conclusions. It is nevertheless believed that it does provide certain indications of the positive potential of 'soft modelling' for early stages of design and leaves the door open for future research on this theme. The research has also reinforced the understanding that designers' capacity in the larger context of industry is limited, and that there is a need for further integration of professions in the development of new products. Early stages of design are an appropriate time for that integration, which therefore requires important changes in the individual's approach to the task, and the training and education to achieve it.

Lastly, as a collateral and unintended outcome, the research has produced a novel method to capture, analyse and display the designers' working processes in a completely visual manner, that the author hopes will be useful for future researchers in the exploration of the designers' way of solving complex problems.

Chapter 9 – TROPHEC AND SOFT MODELLING FOR EARLY STAGES OF DESIGN

9.1. – TROPHEC DEVELOPMENT AND ITS LIMITATIONS

Sustainable design, or producing solutions for users' problems or needs within a framework of sustainable development, can benefit from many different approaches, service design, consumer behaviour design or systems design just to mention a few, all have their intrinsic value and all should be seen as complementary. But when designers reach as a conclusion the need of producing a physical object, all face similar challenges, great amount of information and interconnected variables are challenging to synthesise. It is in moments like this that tools can become essential to assist designers in reaching an optimal solution. This research focused in proposing a new way of synthesising and processing this complexity. The findings and contributions in the previous chapter reveal that the proposed tool is not yet fit for purpose, this chapter discusses the conditions in which the research took place that led to this, as well as provide recommendations for future soft modelling tools development.

In page 135 figure 4.2 depicts the time line of this research. In it can be seen how Trophec was developed within the second half of the first year. This was mainly due to the researcher's previous work, and the initial findings in the literature review, where two overwhelmingly clear needs were identified: incorporating sustainability criteria in early stages, and doing so in a life cycle approach appropriate for that period of new product development. The latter responded to the findings of multiple research in regard to the high level of complexity of the available tools, which in turn requires specialised training and investment of a significant period of time to its use, this counted in days and some cases even weeks, which is completely inappropriate for the early stages. Therefore, a 'soft modelling' approach to cope with this complexity was selected.

Nevertheless, the literature review continued all along the three years of this research, therefore, the full list of recommendations for eco-design tools compiled in chapter two page 99 was not fully developed until the tool was finished and in some cases the testing of the tool was being performed, a fact that resulted in a limited and not yet appropriate solution for the final stated purpose. Just like any other product development, it is required to test the product and iterate in order to improve until the desired outcome is reached. Due to this research time and resources limitations Trophec is only in its first version, and requires considerable improvements that will only be achieved through further iterations of testing and redesign.

The lack of a clear and consistent effect of the tool in the designers' working processes is not believed to be because of a flaw in the fundamental principles lying behind the idea of a tool such as Trophec, but because of the mentioned lack of time and resources to appropriately produce an effective solution for a complex tool like Trophec; one single iteration on its design process is clearly not enough.

Therefore, this research's contributions are set as the identified initial conditions that could potentially lead to a more robust results and clear influence of a soft modelling tool for early stages of design in future research.

After all these experiences and reflections it is therefore proposed in the next section of this chapter a series of improvements for future soft modelling tools for early stages of new product development.

9.2. - IMPROVEMENTS FOR FUTURE 'SOFT MODELLING' TOOLS FOR EARLY STAGES OF NEW PRODUCT DEVELOPMENT

As a result of the participants' experiences and the analysis of the sessions, several areas of improvement were identified.

It is important not to lose track of the purpose of a 'soft modelling' tool - the natural inclination to move towards more conventional LCA assessment tools could be detrimental to the effort and achievements made so far. A list of potential improvements is presented below, organised according to the importance of each point detected in this research, and with the aim of assisting designers at early stages of design. Nevertheless, the previously discussed findings support the idea of enlarging the scope of the tool to include other professions beyond design.

There are four potential improvements that are considered basic for a next version of the tool for future research. These are:

- Highlight the 'connections' within a cycle, the relationship between the materials selected, the manufacturing processes and the recycling strategy. It is highly relevant to make evident, for example, by blocking some functions, that some materials are not compostable or recyclable. This together with better education about the importance of returning all materials to their natural or technological cycles (McDonough and Braungart 2002), and in general low entropy design practices could be key in order to achieve better sustainability practices.
- Remove the linearity of the process. Currently Trophec starts with materials and each step is sequential. In the test some users attempted to start cycles in other

steps, particularly in recycling. This must include the recommendations of the previous point, therefore a user could define transport, or recycling alone, but making a clear unmistakable notice of the need to define the other steps in order to get final or more accurate impact results, and the commitments that those specific decisions imply in other steps.

- Simplify even further the interface. Several times the low-speed response and the positive point of the clarity of the colour coding was mentioned, but it was also declared by some participants, and detected in the analysis, that further improvements could provide even greater performance. In general, the fewer, more 'visual' elements the better, therefore a simpler and clearer glossary (possibly with just icons), specifying if the material is upcyclable and/or compostable, as well as the principal sources are highly desirable. The selected materials and manufacturing processes appeared continuously in the screen with icons, some of them allowed the user to increase and decrease the amounts of each selection; these proved to be too small and prompted several errors. Therefore a simplification of the information and a different sequence of operations are needed. Similarly with the manufacturing processes, simpler examples with machinery could improve the user's understanding. Lastly in the sequence of selections in the pop up window, there is a lack of consistency with the variables could be added, and the ones that are the same for all processes (country of manufacture and number of products to manufacture per day).
- Provide a downloadable version of the software in the form of an application for personal computers and mobile devices. The challenge for the tool as still relevant for research is how to track users' performance. The information should be retrievable by the researcher(s) in order to process it and analyse it.

The next list of changes is a result of direct recommendations of users or improvements noticed in the analysis. These are not considered essential, but desirable, and special care must be paid not to unnecessarily increasing the complexity of the visualisation and sequence of operations. One possibility is to add 'levels' of complexity, where users could decide, if they are in early stages, to use the simpler and faster 'level'. As the level of complexity in the product development increases, the information and complexity of the analysis of the life cycle and its impact could also be increased.

- Add more materials: leather, paper, cardboard, concrete, cement, bricks, copper, brass, bronze, probably differentiate some plastics and rubber, and differentiate some natural fibres.
- The software output range in relation to scales of impact is very large in correspondence to the also vast range of product types, and it was detected that having only one scale of comparison in many occasions led to a misleading

understanding of the impact. Therefore, one possible solution is to give as an option scales of products, where the visualisation is scaled up or down to better appreciate the details.

- Materials performance comparison: In order to make more informed decisions a simple and quick comparison of the main characteristics of materials could be useful. Some of these might include whether materials are upcyclable or compostable, their strength (tensile and friction), durability (UV and other factors), melting point and if possible, costs.
- Transport: Add the information of the principal container sizes and include a simple calculator, which could inform the users of pertinent changes in packaging size in order to increase efficiency in the number of products that would fit a particular container.
- Allow the option of inputting multiple transport types as well as the distance of each, by typing directly the amount, or if the distance is unknown by setting two points on a map.
- Add an electric energy calculator. It was sometimes difficult for users to know the difference between energy and power, and so a simple calculator could be added to aid them set the total amount of energy used by a product, depending on the life span and the power it requires to operate.
- Add the possibility of setting cost to different variables, and perform final calculations. Having costs already set in the software is highly complex, and the prices vary by country and fluctuate regularly, therefore, the value needs to be defined by the user. However, adding the fields to input these values and the final calculation of cost is a viable possibility.
- Remove or modify the business model step. As this research has shown, in many cases the designers do not define the connection between the sustainability of a product and the business model. The proposed 'Trophic Models' proved to be too complex and unfamiliar as a concept for practical use. A simpler way of highlighting these connections must be found.

Lastly there is one more list of possible modifications to the tool related to the possibility of providing assistance (with a 'soft modelling' tool) to other professionals within a company. As stated by some participants, some steps in the life cycle of a product are defined by different, usually unconnected areas or departments within a company. It is rare to find within a company a specialist who controls or guides the entire process and allows the different areas to realise these connections and to make better, more sustainable decisions.

- Investigate and apply the appropriate language and information for different professionals (managers, marketers, engineers, etc).

- Allow different ‘levels’ of complexity and appropriate language when communicating the cycle characteristics to other areas of the company. These descriptions should not and need not be the same.

APPENDIX

Appendix A: SCHEDULE OF ACTIVITIES – NORTHUMBRIA UNIVERSITY TEST

Workshop starts at 9:30 and should end at 12:25

9:20 – 9:30 Students arriving to room CCE2-103

9:30 – 9:35 Welcome and signing consent forms:

After reading the welcome please sign the consent forms provided

Thank you all for helping us today in this workshop.

This is part of a PhD research project, currently under development at the School of Design of Northumbria University.

This task is very simple. We will ask you to propose solutions, just by free hand sketching, for a product described in a brief we will provide in short.

The group is going to be divided into 3 sub-groups who will then work in different rooms. Each sub-group will be organized in teams of 3 members.

In each sub-group ONE of the teams will be video-recorded.

Once the task is finished all data will be kept private at all times, no information will be shared with others, without previously soliciting your consent.
All information will be used to obtain aggregated data, making it impossible to identify single participants; the data will be kept in secured storage for a maximum of three years and later destroyed.
The research outcome will be used in some publications, e.g. Thesis, and possible journal paper, but personal data will never be revealed without previously soliciting your consent.
You can withdraw your participation at any time without any form of penalties or obligations.

Now we will ask you to please complete and sign the consent form INDIVIDUALLY.

9:35 – 9:45 Forming groups:

While students are teaming up co-researchers team leaders individuate by position in the room which teams they will engage.

Picking up signed consent forms.

Now we will ask you to form groups of 3 or 4 persons, you can team up with anyone you want.

9:45 – 10:05 Moving to other rooms (C-A to EBA-103 and C-B to CCE2-412)
TA stays in CCE2-103:

Now it is time to move to the other rooms, please follow your research team

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From this section next reading by researchers team head

9:45 – 10:10 JUST TA: Distribute and answering the entrance survey INDIVIDUALLY + Knowing Trophec Showing the video (6 min) and letting them play around until 10:05

10:05 – 10:10 Distribute entrance survey and colour pen set while seating.
Co-researchers individuate which student's team will follow by their position on the room, if needed, reposition them so you have an easier look. Name the teams by communicating it to the team members:
For CA= A1, A2, A3, A4
For CB= B1, B2, B3, B4
For TA= T1, T2, T3, T4, T5

10:05 – 10:10 JUST CA AND CB: Answering the entrance survey INDIVIDUALLY

While the survey is being answered co-researchers setup the video camera. The video recorded team should be placed in the quietest position in the room.

Loo visits to be taken now if needed.

The first activity is completing a short survey. There are no right or wrong answers, just check the boxes that you feel relate to your thinking.
Please use the colour pen you have been assigned, do not exchange pens. If your pen runs out, please ask for another of the same colour.

10:10 – 10:15 Reading the design brief, instructions and Q & A:
While reading distribute the working sheets, brief and for CB only the raw data sheet.
Pickup entrance survey.

You will be given a number of A4 sheets. They are numbered sequentially. Please keep to the order.
Use the sheets to draw or write anything, is to be shared across all team members.

We kindly ask you to register as much as possible about what is happening and what your team is discussing and thinking.

Please use the colour pen provided, do not exchange pens.

At the top of each sheet there is a small scale which reads: “close – far”

Please, each time you change sheet state, by making a cross in ONE square, “how close your team FEELS they are to achieving their final solution”.

Please use only the front of the sheet if you need more sheets we will provide them.

10:15 TEST START
TURN ON THE VIDEO CAMERA!

Now you can start to work on your project. We will warn of the test end 5 minutes before the end.

You have 1 hour and 40 minutes to finish your proposal.

Please remember: there are no right or wrong answers. All contributions are equally valid and important.

Please use the colour pen provided, do not exchange pens.

11:55 You have 5 more minutes

12:00 TEST FINISHES

12:00 – 12:20 Retrospective analysis INDIVIDUALLY:
While the students write provide the exit survey

Now we will ask you to individually write on the reverse side of the A4 sheets, whatever you may have thought, or didn’t have the chance to express or draw, at the time the related sheet was completed. Help yourself remember what was happening by looking at the content of the sheet front. If you can, please state where that particular insight came from.

Please use the colour pen provided, do not exchange pens.

Please work in sequence and circulate all the sheets among all team members.

You have 20 minutes for this exercise.

12:20 – 10:25 Answering the exit survey INDIVIDUALLY:

Last activity is answering one exit survey.
Please use the colour pen provided, do not exchange pens.

12:25 – 12:25 Debriefing, Q&A:
While debriefing pickup all the material: working sheets, surveys, pens, etc.

The task you just finished is part of a PhD project that is aiming to inform: In what ways the design process may be affected by challenging designer's mental set by means of a software application like Trophec?

Trophec has been specially developed for this research.

Two of the groups were control groups, and one was a test group. We remind you that all data will be used only for academic purposes only.

If you gave us your email in the first survey we will keep you informed about the progress of this research.

If you want to contact the research investigators, please do so at: trophec@trophec.com.
If you want to learn more about the software and use it for free go to: www.trophec.com

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12:25 Dismiss:
Could please the head of the team collect all material and return it to Vic…

That's all folks. Thank you very much for your cooperation!

Appendix B: SCHEDULE OF ACTIVITIES – PROFESSIONALS AND RCA TEST

0.00 Students arriving to room

0.00 – 0.05 Welcome and signing consent forms:

After reading the welcome please sign the consent forms provided

Thank you all for helping us today in this workshop.
This is part of a PhD research project, currently under development at the School of Design of Northumbria University in collaboration with the Royal College of Art.

This task is very simple. We will ask you to propose solutions, just by free hand sketching, for a product described in a brief we will provide in short.

The team will be video-recorded, just capturing your hands, computer screen and voice.

ONLY 2nd AND 3rd TEAMS:
The exercise will be divided in three steps:

1.- Concept generation: all possible ideas you can envision.
2.- Refinement: select ideas (1-2-3-?) and develop them.
3.- Definition: work out all details of a final solution.

At the end of step one and two you will be ask to use the software “Trophec” to help you analyse your concepts regarding innovation and sustainability.

ONLY 3rd TEAM:
In your final solution it is COMPULSORY to include how your product will be deal with at the end of its life: recycling it, trashing it, look on Trophec end of life options!

Your final solution should be presented in an A3 sheet.
Once the task is finished all data will be kept private at all times, no information will be shared with others, without previously soliciting your consent.
All information will be used to obtain aggregated data, making it impossible to identify single participants; the data will be kept in secured storage until useful for this research and later destroyed.
The research outcome will be used in some publications, e.g. Thesis, and possible journal papers, but personal data will never be revealed without previously soliciting your consent.

You can withdraw your participation at any time without any form of penalties or obligations.

Now we will ask you to please complete and sign the consent form INDIVIDUALLY.

0:05 – 0:10 Distribute entrance survey and colour pen set. Answering the entrance survey INDIVIDUALLY

0:10 – 0:25 Knowing Trophec. Showing the videos (7:30min) and letting them play around.

The first activity is completing a short survey. There are no right or wrong answers, just check the boxes that you feel relate to your thinking.
Please use the colour pen you have been assigned, do not exchange pens. If your pen runs out, please ask for another of the same colour.

0:25 – 0:28 Reading the design brief, instructions and Q & A:
While reading distribute the working sheets, brief. Collect up entrance surveys.

You will be given a number of A4 sheets. They are numbered sequentially. Please keep to the order.

Use the sheets to draw or write anything, is to be shared across all team members.

We kindly ask you to register as much as possible about what is happening and what your team is discussing and thinking.

Please use the colour pen provided, do not exchange pens.

At the top of each sheet there is a small scale, which reads: “close – far”

Please, each time you change sheet state, by making a cross in ONE square: “how close your team FEELS they are to achieving their final solution”.

Please use only the front of the sheet if you need more sheets we will provide them.

0:28 TEST STARTS - Only teams 2 and 3: 1.- Concept generation: all possible ideas you can envision.

TURN ON THE VIDEO CAMERA!

Now you can start to work on your project. We will let you know when we are 10 minutes before the end.

Only team 1: You have 1:20 to finish your proposal.

Only team 2 and 3: You have 20 minutes for this first step.

This is the concept generation step: all possible ideas you can envision.

Please remember: there are no right or wrong answers. All contributions are equally valid and important.

Please use the colour pen provided, do not exchange pens.

0:48 First step finishes

0:48 – 0:58 Use of Trophec

The objective now is to use Trophec in order to create the life cycle of the idea-s more appealing to you.

You have Only 10 minutes for this step. Please save the cycles you create using the icon n the top of your screen.

0:58 TEST resumes 2.- Refinement: select ideas (1-2-3-?) and develop them.

This is the refinement step: select ideas (1-2-3-?) and develop them.

Please remember: there are no right or wrong answers. All contributions are equally valid and important.

Please use the colour pen provided, do not exchange pens.

1:18 First step finishes

1:18 – 1:28 Use of Trophec

The objective now is to use Trophec again in order to refine the life cycle of the idea-s more appealing to you.

You have Only 10 minutes for this step. Please save the cycles you create using the icon n the top of your screen.

1:28 TEST resumes 3.- Definition: work out all details of a final solution.

This is the definition step: work out all details of a final solution.

Please remember: there are no right or wrong answers. All contributions are equally valid and important.

Please use the colour pen provided, do not exchange pens.

Remember you need to “present” your final idea in the A3 sheet provided.

1:38 You have 10 more minutes - Remember you need to “present” your final idea in the A3 sheet provided.

1:48 TEST FINISHES

1:48 – 1:58 Retrospective analysis INDIVIDUALLY:
While the students write provide the exit survey

Now we will ask you to individually write on the reverse side of the A4 sheets, whatever you may have thought, or didn’t have the chance to express or draw, at the time the related sheet was completed. Help yourself remember what was happening by looking at the content of the sheet front. If you can, please state where that particular insight came from.

Please use the colour pen provided, do not exchange pens.

Please circulate all the sheets among all team members.

You have 10 minutes for this exercise.

1:58 – 2:03 Answering the exit survey INDIVIDUALLY:

The last activity is answering one exit survey.
Please use the colour pen provided, do not exchange pens.

2:03 – 2:05 Debriefing, Q&A:
While debriefing pickup all the material: working sheets, surveys, pens, etc.

The task you just finished is part of a PhD project that is aiming to inform: *How is the designer working process affected when sustainability-related information is presented through means of an online "soft modelling" software (Trophec)?*

Trophec has been specially developed for this research.

If you gave us your email in the first survey we will keep you informed about the progress of this research.

If you want to contact the research investigators, please do so at: trophec@trophec.com.
If you want to learn more about the software and use it for free go to: www.trophec.com

That is all. Thank you very much for your cooperation!

Appendix C: INITIAL SURVEY SAMPLE

1.- Gender: F M

2.- Years of professional experience:____________

3.- Have you ever received special training in sustainable design? Yes No

4.- Please indicate how interested you are in applying sustainability for new product development in your professional practice:

Considerable Interest	Moderate Interest	Some Interest	Little Interest	No Interest

5.- Please indicate how easy you find applying sustainability for new product development in your professional practice:

Very Easy	Moderate Easy	Somehow Easy	Little Easy	No Easy

6.- Which are the main reasons?

Please answer the next two questions:

1 .- Which of the following points you normally consider when designing a new product?

(tick all that may apply)

Materials Selection □

Production Processes □

Recycling and reuse □

Transport means □

Social issues □

Increase product lifespan □

Reduction of waste in production □

Possible business systems □

Biodiversity □

2 .- How much time do you regularly spend in each of the following phases of product development?

(Suppose you have 30 working days to fully finish your project)

	none	1 days	2 days	3 days	5 days
Looking to inspiration sources	□	□	□	□	□
Identifying the problem	□	□	□	□	□
Conceptualisation	□	□	□	□	□
Exploration/refinement	□	□	□	□	□
Definition/modelling	□	□	□	□	□
Communicating the idea	□	□	□	□	□
Getting ready for production	□	□	□	□	□

THANK YOU!

If you want to be updated about this research please write here your Email:

____

Appendix D: FINAL SURVEY SAMPLE

TEAM:_________

Now that you know **TROPHEC** please answer the next two questions again:

1 .- Which of the following points you normally consider when designing a new product?

(tick all that may apply)

Materials Selection	◻
Production Processes	◻
Recycling and reuse	◻
Transport means	◻
Social issues	◻
Increase product lifespan	◻
Reduction of waste in production	◻
Possible business systems	◻
Biodiversity	◻

2 .- How much time do you regularly spend in each of the following phases of product development?

(Suppose you have 30 working days to fully finish your project)

	none	1 days	2 days	3 days	5 days
Looking to inspiration sources	◻	◻	◻	◻	◻
Identifying the problem	◻	◻	◻	◻	◻
Conceptualisation	◻	◻	◻	◻	◻
Exploration/refinement	◻	◻	◻	◻	◻
Definition/modelling	◻	◻	◻	◻	◻
Communicating the idea	◻	◻	◻	◻	◻
Getting ready for production	◻	◻	◻	◻	◻

Appendix E: WORKING SHEET SAMPLE

Team:

far □ □ □ □ □ close

1

Appendix F: RAW DATA SHEET SAMPLE

If you are interested in designing more sustainable products here you have access to information that will help you achieve it.

Materials

Plastics:
British Plastics Federation: http://www.bpf.co.uk
Metals:
British Geological Survey: http://www.bgs.ac.uk
World Steel Association: http://www.worldsteel.org
International Stainless Steel Forum: http://www.worldstainless.org
International Aluminum Institute: http://www.world-aluminium.org
Woods:
Forest Stewardship Council: http://www.fsc.org
FAO United Nations: http://fao.org
Ceramics:
European Ceramic Industry Association: http://cerameunie.eu
Glass:
British Glass: http://www.britglass.org.uk
Material intensity:
Ritthoff, M. et al. (2002) *Calculating MIPS, Resource productivity of products and services.* Wuppertal Institute for Climate, Environment and Energy.

Others:
World Resources Institute: www.wri.org

Energy:
International Energy Agency**:** www.iea.org
Hammond, G. Jones, C. (2008) *Inventory of Carbon and Energy*. Department of Mechanical Engineering, University of Bath, United Kingdom.

Transport:
Department for environmental, food and rural affairs: www.defra.gov.uk
Boeing company: www.boeing.com
Volvo trucks: www.volvotrucks.com
Maersk: www.maersk.com
Office Rail Regulation: http://www.rail-reg.gov.uk

Countries:
Human Development Index, United Nations Development Program:
http://hdr.undp.org
OCDE: http://www.oecd.org
United Nations Environmental Program: http://www.unep.org
United Nations: http://www.un.org
World Bank: www.worldbank.org
The World Fact Book: https://www.cia.gov/library/publications/the-world-factbook

Appendix G: MULTIPLE CYCLE USERS

USER: Multi-08

		01	02	03
ØRn	Thermoplastic			
ØRnRc	Thermoset	0.2	0.6	
	Bioplastics			0.6
ØRnRc	Composites	0.3		
ØRn	Steel			
ØRn	Stainless			
ØRn	Aluminium			
	HardWood			
	SoftWood			
	NaturalFibers			5
ØRc	Panels			
ØRnRc	Ceramic			
ØRn	Glass			
		VNM	MYS	MEX
	Forming		X	X
	Cutting	X	X X	X X
	Joining	X	X	X
	Finishing	X		
	Assembly	X		
	HandLight	2	1.6	2.7
	HandMed	15	0.8	
	HandHigh		1	0.6
	MechLight			
	MechMed			
	MechHigh			
		VNM	MYS	MEX
	TrUCK			x
	TraIn			
	SHIP	x	x	
	aIrPLane			
	PacKaGInG	12	15	15
	PacKaGInG	27	34	20
	PacKaGInG	10	20	35
	Life	1	1	1
	Uses	365	365	365
	Petrol			
	Electricity			
		MEX	MEX	MEX
	consumers			
	distributors			
	producers			
	compost			
	landfill	100	100	100
	CYCLE	01	02	03
	name	Tenis Adidas	Chancla Puma	Chancla Kin

USER: Multi-09

		01	02	03
∅Rn	Thermoplastic			
∅RnRc	Thermoset			
	Bioplastics			
∅RnRc	Composites			
∅Rn	Steel			
∅Rn	Stainless			
∅Rn	Aluminium	5	5	
	HardWood			
	SoftWood			
	NaturalFibers	5		
∅Rc	Panels			
∅RnRc	Ceramic			5
∅Rn	Glass			
		MEX	MEX	MEX
	Forming			×
	Cutting	× ×	×	
	Joining			
	Finishing			
	Assembly		×	
	HandLight			
	HandMed	15		
	HandHigh		5	5
	MechLight			
	MechMed		5	
	MechHigh			
		MEX	MEX	MEX
	TRUCK	×	×	×
	TRAIN			
	SHIP			
	AIRPLANE			
	Packaging	100	50	1
	Packaging	100	100	1
	Packaging	100	120	1
	Life	15	99	99
	Uses	5,000	5,000	5,000
	Petrol	12	1	1
	Electricity	5	1	1
		MEX	MEX	MEX
	consumers	94	90	100
	distributors	1	3	
	producers	2	7	
	compost	2		
	landfill	1		
	CYCLE name	01 Fibras	02 Aluminio	03 Concreto

USER: Multi-19

	01	02	03	04	05	06	07	08	09
ØRn Thermoplastic		5							
ØRnRc Thermoset	5x3	5		5	5	5			
Bioplastics							5	5	
ØRnRc Composites									
ØRn Steel						5x3			5
ØRn Stainless									
ØRn Aluminium			5x2						
HardWood									
SoftWood									
NaturalFibers									
ØRc Panels									
ØRnRc Ceramic									
ØRn Glass									
	IND	IRN	DZA	PAK	PAK	AUS-PAK	ESP	ESP	FRA
Forming	×	×		×	×		×	×	
Cutting						×			×
Joining			×			×			
Finishing									
Assembly									
HandLight									
HandMed									
HandHigh									
MechLight							5	5	
MechMed	5x2	5		5	5				5
MechHigh			5			5x2			
	CHN	CHN	IND	CHN	CHN	CHN	ESP	ESP	ESP
Truck									
Train				×	×	×	×	×	×
Ship									
Airplane	×	×	×						
Packaging	100	100	111	150	150	150	50	50	50
Packaging	100	10	11	150	150	150	50	50	50
Packaging	100	1	1	150	150	150	50	50	50
Life	30	10	20	5	5	10	10	10	10
Uses	1,000	1,000	999	100	100	200	100	100	100
Petrol	2	1	1	10	10	10	1	1	1
Electricity	2	1	10	1	1	20	1	1	10
	ESP	AGO	IRN	ESP	ESP	ESP	ESP	ESP	ESP
consumers	5	5	5	5	5	5	15	15	15
distributors	20	20	20	35	35	35	50	50	50
producers	20	5	10	10	10	10	20	20	20
compost		20	34	10	10	10	15	15	15
landfill	55	50	31	40	40	40			
CYCLE	01	02	03	04	05	06	07	08	09
name	lego	mecano	KNEX	lego without I	KNEX without I	meccano without I	lego improved	knex improved	meccano improved

USER: Multi-23

		01	02	03
ØRn	Thermoplastic			
ØRnRc	Thermoset			
	Bioplastics			
ØRnRc	Composites			
ØRn	Steel			
ØRn	Stainless			
ØRn	Aluminium		5	5
	HardWood	10 5		
	SoftWood			
	NaturalFibers			
ØRc	Panels			
ØRnRc	Ceramic			
ØRn	Glass			
		PER	CHN	CHN
	Forming		X	X
	Cutting	X	X	X
	Joining		X	X
	Finishing		X	X
	Assembly		X	X
	HandLight			
	HandMed			
	HandHigh			
	MechLight	5		10
	MechMed		10	
	MechHigh		15	15
		PER	AUT	AUT
	truck		x	
	train			
	ship			
	airplane	x		x
	Packaging	100	10	10
	Packaging	100	5	5
	Packaging	100	5	5
	Life	20	1	1
	Uses	1,000	1	1
	Petrol		8	1
	Electricity		277	1
		AUT	AUT	AUT
	consumers	100		
	distributors			
	producers		65	65
	compost			
	landfill		35	35
	CYCLE	01	02	03
	name	wood from Peru	Alu Can (3)	Alu Can 1

USER: Multi-36

		01	02	03
ØRn	Thermoplastic			5 5
ØRnRc	Thermoset		5	
	Bioplastics			
ØRnRc	Composites			
ØRn	Steel		5	
ØRn	Stainless			
ØRn	Aluminium			
	HardWood	60	95 5	
	SoftWood			
	NaturalFibers			
ØRc	Panels			
ØRnRc	Ceramic			
ØRn	Glass		5	
		MEX	AUT/ARG BHR/FJI CRI	AUS
	Forming		X X	X
	Cutting	X	X	
	Joining			
	Finishing			
	Assembly			
	HandLight			
	HandMed			
	HandHigh		205.1	
	MechLight			
	MechMed	5		
	MechHigh			5
		MEX	BWA	BRN
	TRUCK	x		
	Train			
	SHIP			
	airPLane		x	x
	Packaging	80	30	45
	Packaging	50	60	25
	Packaging	60	70	24
	Life	2	7	8
	Uses	300	193	4,000
	Petrol	40		
	Electricity	40		
		MEX	MDA	ISL
	consumers	70	10	100
	distributors	10	10	
	producers	5	10	
	compost	5	60	
	landfill	10	10	
	CYCLE name	01 Chair1	02 Chair2	03 Respaldo

Appendix H: ETHICS RESEARCH APPROVAL

Research Project - Approval Granted https://outlook.office365.com/owa/projection.aspx

Research Project - Approval Granted

DELETE REPLY REPLY ALL FORWARD ...

Research Ethics Submission Portal <web.form@northum Mark as unread

Fri 6/13/2014 1:12 PM

supervisors

To: victor.martinez;

Research Project - Approval Granted

This is an automated email from the Research Ethics Submission Tool. Research project **RE-ADSS-12-130715-51e3fe0169e33** has been granted internal ethical approval.

GLOSSARY

DATA TRIANGULATION

Combination of different sources of data from the same protocol. Its intention is to converge them, so corroboration and correspondences may result in enhanced and clarified results. Complementary data can come from qualitative and quantitative sources, such as researchers observation written in a log or a diary, concurrent and retrospective reports, video and audio recording, etc.

DESIGN PROCESS

A series of steps that guide the production of a design solution. Different authors have described the design process with different number of steps. Nevertheless, a common denominator has been proposed by Self (2011): *Design specification*, often performed by marketing or management in which designers have little influence. *Concept design*, main designers' influence area, where in an open and divergent process new embodiments are explored, as part of an iterative and non-linear process. *Development design*, the evolution of concepts into a more specified design intent, which in essence considers initial product testing and evaluation. *Detail design*, the exact communication and specification of parts for final testing and manufacture.

EARLY STAGES OF NEW PRODUCT DEVELOPMENT

It is understood as the first steps of the design process where concepts are still searched and the general process belongs to a divergent and inclusive character. Early Stages are considered highly important because of this character, can easily include new considerations coming from different flows of information. Early Stages are a rapid, ambiguous and personal process, the information flows, in order to be effective, must coherently interact with it and respond to designers' working culture.

ECO-DESIGN

Refers to the activity of new product development with environmental considerations as one of the main drivers, such consideration could be: materials sourcing impact in biodiversity, air and water pollution in manufacturing, recyclability of materials, etc.

ECO-DESIGN TOOLS

Guidelines, checklist and analytical tools specifically developed to provide aid to designers in their working process in order to include environmental consideration into their designs.

EXTERNAL REPRESENTATIONS

The process of decision-making and learning in a design process require a system of representations as part of the information processing. Designers produce external representations in verbal and non-verbal form. Non-verbal in turn can be figural and conceptual and both can be visual or verbal. Sketches and models are considered external non-verbal representations.

LATERAL & VERTICAL TRANSFORMATIONS

In the design process, ideas can have two different origins: unique new concepts or originated from a previous episode. In the latter a distinction is relevant: lateral transformations are variations but distinctly different, and vertical transformations are reinforcements through explication and detailing.

MATERIAL INTENSITY

Refers to the intensity in the use of resources for the extraction of raw material for industrial manufacture, e.g. in order to obtain one kilogram of wood ready for industrial manufacture, five kilograms of tree and other biotic material are cut in the forest, and almost ten litter of water are used.

MEGA JOULES

Millions of Joules. Joule is a unit of energy equivalent to a 0.00027 Watt/hour, or one Newton/meter

NOMOLOGICAL CONSTRAINS

When identifying the features of a design task environment and criteria, Goel and Pirolli (1989) propose two different constrain natures: Social/political/legal/economic/etc., which are negotiable; and nomological, which are dictated by natural law, hard non-negotiable. From Greek *nomos* + English *–logy:* relating to or expressing basic physical laws or rules of reasoning (Merrian-Webster, 2014)

PRODUCT LIFE CYCLE

All the steps necessary to access and transform raw materials into consumer products, and their eventual discard or recycle.

SKETCH COMPLEXITY

It has been found (V. Goel, 1995) that sketches in early stages of design have a greater level of ambiguity and density, which is beneficial for creativity. The more the work progresses, more detail, specific and non-dense sketches become.

SOFT MODELLING

A simplified description of a system or process in order to gain a more holistic perspective, relates to 'assessing ideas by relating theoretical interest to observations of the world as experienced' (Falk & Miller, 1992).

SUSTAINABLE DESIGN

Refers to the activity of new product development with environmental, social and economic considerations.

TROPHIC ECONOMICS

Term first coined by Ney (1990). Originally referring to fisheries management from a biological point of view (trophic levels), where the 'feeding' of different species is set by two main factors: determination of source supply and assessment of viability. This term was used in contraction form to name the soft modelling software developed for this research 'Trophec'.

USERS: REGISTERED, ACTIVE, MULTI-CYCLE

In the soft modelling software developed for this research (Trophec), three different user types were determined: Registered – all users that opened an account; Active – all registered users that saved cycles; Multi-cycle – all active users that saved more than one cycle.

WATTS PER HOUR

A unit of energy equivalent to one Watt (power), operating for one hour (Merrian-Webster, 2014).

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